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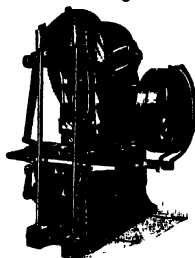
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REFRACTORIES FOR FURNACES, CRUCIBLES, ETC.

DESCRIBING THE CHARACTERISTICS OF
THE CHIEF RAW AND MANUFACTURED
REFRACTORY MATERIALS

AND THE PROCESSES AND MACHINERY
EMPLOYED IN THEIR PRODUCTION

BY

ALFRED B. SEARLE

CONSULTING TECHNOLOGIST AND TECHNICAL ADVISER ON CLAYS,
CLAY PRODUCTS, AND ALLIED MATERIALS



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PREFACE

REFRACTORY materials are used in almost every industry in which heat is employed, and they are equally as necessary to the construction of the domestic fireplace as to that of the largest furnaces employed in steel-making. Yet the nature, properties and methods of manufacture of these widely-used materials are so little known, that few people are aware of their enormous importance.

Without refractory materials no locomotives could transport either goods or passengers, no boilers could be built to supply steam for the multifarious purposes for which that wonderful material is used. Without refractory materials, there could be no metals, and civilization would never have advanced beyond the Stone Age. Indeed without materials sufficiently refractory to meet his simple needs, even primitive man could not long exist for, even in the most elementary form of human life, pots—capable of being placed on a fire without damage—for cooking purposes appear to be essential.

Some manufacturers and inventors at the present day complain that modern requirements are so severe that industrial progress is hampered by lack of materials which possess a sufficiently high refractoriness. Whilst there is some truth in this contention, it would be more accurate to say that the limitation does not lie with the materials available, so much as in a widespread ignorance of their nature

PREFACE

and properties. Speaking generally, men of great enterprise have given little or no thought to the possibilities latent in refractory materials, and the largest users of these materials and the articles made from them pay more attention to securing a "cheap" article, than to taking effective means to supply those of superior quality.

During recent years, great progress has been made in the recognition, by users, of the importance of refractory materials, particularly for furnaces, but the subject is still in an early stage of development. This is due to its great complexity and to the very severe conditions to which refractory materials are subjected.

They are required to remain unchanged when everything with which they come in contact is either reduced to a molten mass or is volatilized or burnt away. They are expected to retain their shape when subjected to the pressure of many tons of molten steel, to the corrosive action of highly basic slags and to the destructive effects of the hottest flames. The most painstaking attention is paid to the scientific testing of steel and many other substances, but the refractory materials—without which modern industry would be impossible—are bought with a disregard of tests and specifications which is simply astounding.

Under these circumstances, it is remarkable that so few serious failures occur, and the manufacturers of refractory articles can desire no better testimonial to their general ability to serve their customers well, than the fact that the elaborate precautions taken

in the purchase of other materials are considered to be unnecessary where refractories are concerned. How far the continuation of the method of purchasing goods on "reputation" rather than on intrinsic worth, is justifiable, is a matter which each purchaser must decide for himself. A careful reading of the following pages will, it is hoped, enable most readers to reach a definite conclusion on the matter.

In order that this book may be of the greatest possible value to readers who approach the subject for the first time, all descriptions have been kept as simple as possible considering the complexity of the subject, but the more exhaustive treatises mentioned in the Bibliography—especially the author's treatise on *Refractory Materials* (Griffin)—should be referred to for many important details.

The arrangement of the book is unusual, articles of a refractory nature being described prior to the materials of which they are made. This arrangement has been adopted because the author has found, from experience, that students are better able to appreciate the purpose of different processes if they are first acquainted with the properties of the finished products. In this way, they proceed on sound educational lines from the known to the unknown and make far more rapid progress than if they follow the apparently more logical process, and commence with the raw materials.

ALFRED B. SEARLE.

SHEFFIELD.

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REFRACTORIES FOR FURNACES, CRUCIBLES, ETC.

CHAPTER I

FIREBRICKS AND BLOCKS

AN essential quality of all furnace linings, and of other articles to which the term "refractory" is applied, is that they shall be able to withstand the temperature to which they are exposed when in use. This is by no means the only important property which they are required to possess, but it is the one which is specially significant.

The term "refractory," as applied to furnace linings and to other articles or materials used at high temperatures, has a meaning somewhat different from that found in most dictionaries. It is employed to indicate that the articles or materials to which it refers are capable of resisting the conditions of heat, corrosion, and abrasion to which they are likely to be subjected. In a still more restricted sense, it is applied to those articles or materials which show no obvious signs of fusion after being heated slowly to a temperature of 1580° C. or 2876° F. This temperature has been selected quite arbitrarily on account of its convenience, more especially with regard to firebricks and other articles made of fireclay.

Refractoriness: Seger Cones.

The refractoriness of a material is determined by making it into a small tetrahedron, i.e. similar to a pyramid but with a triangular base and only three sloping sides, about $2\frac{1}{2}$ in. in height, and $\frac{1}{2}$ in. along each side of the base (Fig. 1). This test piece may be made by mixing the ground material with a



FIG 1.
SEGER CONE.

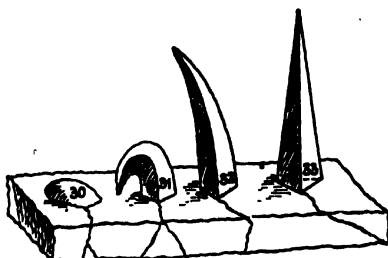


FIG. 2.
SEGER CONES AFTER USE.

little dextrin and water, so as to form a paste, and then moulding it in a brass or other mould; or a piece may be chipped off a larger article, and ground or cut to the required shape.

The test piece is heated along with similarly shaped pieces, termed "Seger cones," which are made of finely-ground mixtures of clay, flint, and felspar in such proportions as to produce a series of cones which form a definite scale of refractoriness. Such cones can be purchased from dealers in potters'

FIREBRICKS AND BLOCKS

materials; they should be sold under guarantee as to their accuracy, as serious errors may result from using unreliable cones. The test piece and a series of cones are fastened on to a suitable tile or slab with a little paste, made by mixing china clay and calcined alumina with water, and when thoroughly dry they are heated in a clean oxidizing atmosphere in such a manner that the temperature rises steadily at the rate of about 50°C . in five minutes. They are examined from time to time, and when the test piece has bent over sufficiently for its apex to be almost on a level with its base (*see* 31 in Fig. 2) the test piece and cones are immediately removed from the furnace. The Seger cone which has been bent to an equal extent is the one regarded as having the same refractoriness as the test piece. Any cones which have collapsed through overheating (*see* 30 in Fig. 2) are less refractory than the test piece, whilst the cones which have not bent so much as the test piece (*see* 32, 33 in Fig. 2) are of greater refractoriness.

Instead of waiting for the test piece to bend in the manner described, it is sometimes considered better to withdraw it from the furnace when a prearranged temperature has been reached, and to examine it for signs of fusion. The sign of fusion usually selected is the loss of angularity of the edges of the test piece. If no fusion has occurred, another test piece is heated to a higher temperature, when it is again examined. This procedure is continued until definite signs of fusion are observed, when the cone which has bent to the position of 31 in

Fig. 2 is taken as the refractoriness of the test piece.

If the test piece shows signs of fusion when first withdrawn from the furnace the test must be repeated and the first withdrawal made at a lower temperature.

The term "squatting temperature" is sometimes used instead of "refractoriness."

In any report of the refractoriness of a material it should be definitely stated which of these points—the bending of the test piece or the first observed sign of fusion—is used as a basis of comparison.

When skilfully prepared, Seger cones are very convenient, but their indications must not be misinterpreted. They are commonly regarded as corresponding to certain temperatures (Table I) but this is only the case when they are heated under

TABLE I.—SQUATTING TEMPERATURES OF SEGER CONES WHEN HEATED UNDER STANDARD CONDITIONS.

Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.
022	600	1112	07a	960	1760	9	1280	2336	29	1650	3002
022½	650	1202	06a	980	1796	10	1300	2372	30	1670	3038
020	670	1238	05a	1000	1832	11	1320	2408	31	1690	3074
019	690	1274	04a	1020	1868	12	1350	2462	32	1710	3110
018	710	1310	03a	1040	1904	13	1380	2516	33	1730	3146
017	730	1346	02a	1060	1940	14	1410	2570	34	1750	3182
016	750	1382	01a	1080	1976	15	1435	2615	35	1770	3218
015a	790	1454	1a	1100	2012	16	1460	2660	36	1790	3254
014a	815	1499	2a	1120	2048	17	1480	2696	37	1825	3317
013a	835	1535	3a	1140	2084	18	1500	2732	38	1850	3362
012a	855	1571	4a	1160	2120	19	1520	2768	39	1880	3416
011a	880	1616	5a	1180	2156	20	1530	2786	40	1920	3488
010a	900	1652	6a	1200	2192	26	1580	2876	41	1960	3560
09a	920	1688	7	1230	2246	27	1610	2930	42	2000	3632
08a	940	1724	8	1250	2282	28	1630	2966			

FIRECLAY BRICKS

"standard conditions" as regards the atmosphere inside the furnace and the rate of heating. In large industrial furnaces the cones usually indicate slightly higher temperatures than those actually reached. For these reasons, it is better to report refractoriness in terms of Seger cones and not with reference to a scale of temperature.

FIRECLAY BRICKS

The best known refractory materials are fireclay bricks—often termed *firebricks*, though this word includes bricks made of silica, alumina, magnesia, and other refractory materials. Such bricks are used whenever a structure is required to withstand the action of heat, as in furnace linings, hearths of furnaces, boiler settings, domestic fireplaces, etc.

Fireclay bricks, as their name implies, are made of fireclay which is selected, ground, mixed with water, shaped either in hand-moulds or in presses, dried and then burned at a temperature corresponding to the indicating point of Seger cones 5 to 15. Firebricks which are burned at Cone 5 are liable to shrink seriously when heated to a much higher temperature in use, but are quite suitable for many purposes where firebricks are required though the conditions are by no means severe. Fireclay bricks

* The conditions generally regarded as "standard" are that the test-piece and cones must be heated in a clean oxidizing atmosphere, the temperature rising steadily at the rate of 50° C. in five minutes throughout the whole period of heating. If the temperature rises too rapidly the test-piece will appear to be more refractory than is actually the case (see p. 13).

which have been burned at a higher temperature are much more nearly constant in volume when used under more trying conditions.

Colour.

Fireclay bricks are usually of a pale cream or buff colour, if insufficiently burned, but those which have been raised to higher temperatures are reddish or brown in colour, with numerous black spots of a slag-like material derived from the iron pyrites originally present in the fireclay.

The colour of fireclay bricks is of no importance so far as their use is concerned, but it is often an indication as to whether they have been burned at a sufficiently high temperature. It is by no means always reliable but, in the majority of cases, a dark spotty brick will prove more nearly constant in volume and of greater technical usefulness than a pale brick of uniform colour.

Shape.

The shape of fireclay bricks is of great importance for some purposes, because bricks of irregular shape require to be laid with large joints, and as the joints are the weakest part of a furnace or similar structure, and the ones which are first destroyed by corrosion and abrasion, it is essential to keep them as thin as possible. Hand-moulded firebricks are found, by experience, to be more durable than machine-pressed bricks in many instances, though this is not always the case. It is generally agreed that all fireclay

bricks should be reasonably accurate in shape, and that they should not vary by more than $1\frac{1}{2}$ per cent of the standard length or more than $2\frac{1}{2}$ per cent of the other dimensions, unless they are sold as "not according to standard."

Size.

The dimensions for fireclay bricks mentioned in the Standard Specification of the Institution of Gas Engineers are 9 in. by $4\frac{1}{2}$ in. by 3 or $2\frac{1}{2}$ in. thick. These are usually accepted as a standard for all fireclay bricks in the United Kingdom.

Texture.

The texture of fireclay bricks is of great importance as their durability depends largely thereon. It is obvious that all the surfaces should be reasonably true and free from flaws, holes and that peculiarly irregular surface known as "winding." When a brick is broken it should contain no "holes" of such a size to indicate defects in manufacture. If the bricks are composed wholly of very minute particles they will tend to resist corrosion and the chemical action of slags, etc., and any such action will occur at a fairly uniform rate. If, on the other hand, the bricks are composed of large and small particles, the former will tend to fall out as the brick wears away or is corroded, leaving relatively large hollows or "pockets," so that the average rate of attack is increased.

Unfortunately, bricks composed wholly of extremely small particles are more sensitive to sudden

changes in temperature and tend to crack or spall when suddenly heated or cooled. This defect is much less serious in bricks made of clay than in those made of some other materials, and generally it does not need serious attention so far as fireclay bricks are concerned.

Bricks composed wholly of finely-ground fireclay naturally have a very fine texture. It is seldom considered desirable to grind the material to a uniform fineness, so that most firebricks are composed chiefly of fine grains with a variable proportion—seldom exceeding 30 per cent and occasionally as low as 5 per cent—of particles of 0.05 to 0.25 in. diameter. Occasionally still larger pieces are found in fireclay bricks but they are undesirable and are usually accidental. Some manufacturers—and most users—of fireclay bricks consider that $\frac{1}{4}$ in. is the maximum size of fragment ordinarily permissible in firebricks, though a very small number of pieces $\frac{1}{4}$ in. diameter are not prohibited if they are well below the surface.

These coarse particles may be composed of quartz or some other form of siliceous rock occurring in association with fireclay, or they may be composed of *grog* (p. 89). In suitable proportion they form a kind of skeleton to the brick, the finer particles then acting as a bond or matrix so as to produce a structure of great strength and durability.

The texture may be conveniently examined by breaking a brick, grinding the broken surface flat on a carborundum grindstone, and then cementing a sheet of thin window glass on to it by means of Canada balsam. A similar effect

FIRECLAY BRICKS

may be obtained by polishing the fractured surface, but this is much more troublesome and the result is scarcely worth the trouble.

A magnifying glass or a low-power microscope is convenient when examining the texture of bricks which have been prepared in this manner. A magnification of 10 times is ample for most purposes.

In addition to the relative sizes of the various particles, the proportion of partially-fused or vitrified material in the bricks is of great importance. When the temperature is sufficiently high and the heat in the kiln is sufficiently prolonged, some of the constituents of the brick begin to melt and gradually form a glassy or slag-like material. When the amount of this substance is sufficient to fill all the interstices between the other particles of which the brick is composed, a dense, impervious mass is produced and the brick is said to be "fully vitrified." This state is seldom reached with fireclay bricks, but it is the normal condition of porcelain and of many engineering bricks. In this sense the term "vitrification" is used to indicate the gradual formation of a molten glassy or slag-like material, which flows among the interstices in the bricks and will eventually fill them if the conditions of heating are favourable. If a firebrick is exposed to sufficiently high temperatures when in use the vitrification will continue and, under suitable conditions, so much fused or vitrified material may be formed that either the brick loses its shape or the molten material gradually gathers into large, "drops" which may eventually fall away.

This form of destruction may be readily observed in the interior of the roofs of many furnaces and kilns. It is often increased by the action of basic or alkaline materials in the furnace or derived from the fuel (including fine dust). These substances act on the bricks forming new compounds of greater fusibility than the fireclay. Where such substances occur it is important to use firebricks with a dense face, to which bases and alkalies will not readily adhere, and to take the precaution of using a large proportion of coarse and inert material in the bricks. In resisting such attacks a dense texture is of great value, as porous bricks are much more rapidly corroded on account of the greater facilities they offer for the penetration of the corroding agent.

Many attempts have been made to devise a suitable method for comparing the relative effect of various corrosive agents on firebricks, but none of these methods is wholly satisfactory. One of the best consists in cementing an inert cylinder on to the brick, filling the cylinder with the corrosive agent and then heating the brick to a suitable temperature. After the brick has been allowed to cool it is sawn vertically through the cell and the penetration of the slag, flue-dust or other corrosive agent is estimated from the appearance of the sawn surface.

Much may be learned from an exhaustive examination of the textures of firebricks which have been in use for a considerable time, but a detailed description of such an examination and the conclusions which may be drawn from it is beyond the scope of this book. It must suffice here to state that such an

FIRECLAY BRICK

examination usually reveals—often better than anything else—the causes of superiority or deficiency of various firebricks.

Porosity.

Most specifications for fireclay bricks do not mention porosity, yet this property is very important. The porosity is chiefly due to the minute interstices or voids between the solid particles of the bricks, though there is, in addition, a small proportion of "sealed pores" in the particles themselves. Porosity is valuable inasmuch as it increases the resistance of a brick to sudden changes in temperature, but it is harmful where it permits slags or other corrosive agents to attack the bricks.

In most cases, the proportion of pores is less important than their average size, large pores being the most objectionable.

The porosity is usually determined by weighing a dry brick, immersing it in water until saturated, then withdrawing it, wiping off the superfluous water, and reweighing the brick. The gain in weight shows the amount of water absorbed in the pores of the brick; it is usually expressed as a percentage of the original weight of the brick. A more satisfactory method is to calculate the volume of water absorbed and that of the brick, and to express the porosity in terms of percentage by volume.

It is necessary to determine the porosity on whole and undamaged bricks, as the interior of fireclay bricks is much more porous than the bricks as a whole, owing to the presence of a dense, exterior skin.

For most furnace linings, coke ovens, etc., the porosity

of the fireclay bricks used should not be less than 6 per cent by weight, or 12 per cent by volume, though to resist very corrosive slags a much lower porosity may be desirable. Bricks required to withstand sudden changes in temperature can scarcely be too porous.

Volume-Weight and Apparent Density.

The ratio of the weight of a fireclay brick to its volume is closely connected with its porosity. This ratio may be expressed in simple figures by dividing the weight of the brick by that of an equal volume of water, or it may be expressed in "lbs. per cubic foot." A fair average figure for the apparent density is from 1.2 to 1.5, and for the volume-weight from 75 to 94 lbs. per cu. ft.

True Specific Gravity.

The relative weight (compared with water) of the actual particles composing the brick (i.e. the true specific gravity) is much greater than the apparent density of the whole brick; it is usually from 2.4 to 2.7.

Refractoriness.

The refractoriness of fireclay bricks is usually the same as that of Seger cones 26 to 32 (see Table I, p. 4); occasionally fireclay bricks with a refractoriness equal to Cone 34 are found, but they are unusual and seldom consist wholly of fireclay. The higher refractoriness sometimes reported is usually due to an error in the carrying out of the test. If the heating is effected more rapidly than is described

on p. 3, the refractoriness will apparently be higher, but the result will be inaccurate and due to the heat not having had time to penetrate the test piece sufficiently. Hence, it is of the utmost importance to heat the test pieces at a definite and predetermined rate. Fireclay bricks which show signs of fusion when heated to a temperature indicated by Cone 30, conform to the No. 1 grade of refractoriness of the Standard Specification of the Institution of Gas Engineers: fireclay bricks which are less refractory yet show no signs of fusion when heated to a temperature indicated by Cone 26, are classed as No. 2 grade. Bricks which show signs of fusion below Cone 26 are not regarded as "refractory bricks."

The fact that firebricks with a refractoriness of Cone 27 (1670° C.) often prove quite durable in furnaces heated to 1650° C. or above sometimes puzzles those who have not inquired more fully into the matter. The apparent contradiction is due to the fact that all firebricks have a very low thermal conductivity, i.e. heat travels through them very slowly. Consequently, if only the surface of a brick is exposed to the full heat of the furnace, the temperature $\frac{1}{4}$ in. or so behind the surface may be well below the softening point of the material. It is quite possible to raise one end of some firebricks to a white heat and to hold the other end quite comfortably in the hand.

Melting Point.

The melting point of fireclay bricks is seldom determined. It appears to be much higher than the refractoriness or squatting temperature, if large pieces of brick are examined, but if a few grains are heated under the microscope the difference between

the reported "refractoriness" and the fusion temperature or true melting point is much less marked. This is due to the low thermal conductivity of the material (p. 13), which makes it extremely difficult - almost impossible - to obtain the true melting point of a whole firebrick. The impurities in the bricks also tend to combine with the silica and alumina present and to form fusible compounds, each having a different melting point. Consequently a fireclay brick has no sharply defined melting point like that possessed by pure crystalline compounds, but has instead a long "range of fusion."

Care should be taken not to employ the term "melting point" or "fusibility" when referring to the refractoriness of a brick or other refractory material.

Chemical Composition.

The chemical composition of fireclay bricks corresponds very closely to that of the clay of which they are made. The most noticeable difference is the absence of "loss on ignition" and a slight reduction in the amount of soda and potash present. The term "loss on ignition," as its name implies, is the loss in weight which a small quantity of finely-ground material undergoes when heated to a temperature of about 900° C., i.e. to the full heat of a Bunsen burner. This treatment decomposes the clay, causing it to evolve water as one of the products of its decomposition. At the same time, any carbonaceous matter is expelled, any carbonates are either partially or wholly converted into oxides,

and some of the sulphides may be converted into oxides or sulphates.

The slight loss of soda and potash, usually accompanied by a slight loss of silica, is due to the partial volatilization of these materials when the bricks are burned in the kiln. If the same bricks are examined after prolonged use at a still higher temperature than that at which they were burned, a further loss of soda, potash and silica will be observed, though this is sometimes counterbalanced by the absorption of similar materials from the contents of the furnace.

The chemical composition of a fireclay brick shows it to consist of from 60 to 80 per cent of silica : 20 to 35 per cent of alumina : 1 to 2.5 per cent of ferric oxide : 0.5 to 1.5 per cent of lime : 0.5 to 0.7 per cent of magnesia : and 1 to 2 per cent of potash and soda. These variations are due to the differences in the composition of the fireclays used. It will generally be found that fireclay bricks which show more than 55 per cent of silica on analysis, contain a considerable proportion of free silica, though very few British fireclays (other than china clay which is not usually regarded as a fireclay) contain as little as 55 per cent of silica, which would be expected in a brick made wholly of true clay.

The chief use of a chemical analysis of a fireclay brick is to show the proportion of the various impurities present, but as these are generally in the form of compounds, a very careful study of the analytical figures is necessary to obtain a reasonably accurate estimate. Thus, it is usual to stipulate

that fireclay bricks of first-class quality shall not contain more than the following percentages of the materials mentioned—

Lime (CaO)	1 per cent
Magnesia (MgO)	0.6 "
Iron Oxide (Fe_2O_3)	2.5 "
Soda (Na_2O) and Potash (K_2O)	2 "

According to the Standard Specification issued by the United States Bureau of Standards in 1914, if the molecular formula is calculated from the results of analysis, the total number of molecules of lime, potash, magnesia, soda and iron oxide should not exceed one-fifth of the number of molecules of alumina. With an average fireclay brick this is roughly equivalent to a declaration that the sum of the percentages of all the oxides mentioned should not exceed 4.5 per cent.

Fireclay bricks to be used under conditions which do not call for extraordinary refractoriness may contain notably large proportions of these oxides and still prove quite satisfactory in use.

The most obvious impurity in fireclay bricks is fayalite (2FeO SiO_2) an iron silicate which is formed by the oxidation and eventual silicification of the pyrites in the fireclay of which the bricks are made. The fayalite or analogous compounds, forms black, slag-like spots irregularly distributed through the bricks. If the total quantity present does not represent more than 2.5 per cent of iron oxide (Fe_2O_3) its effect on the durability and usefulness of the bricks is practically negligible. Owing to the fact that this black silicate contains only 72 per cent of iron oxide, and that it is widely distributed, most fireclay bricks appear to contain a much larger

proportion of iron compounds than is actually the case. Consequently, such bricks should never be condemned solely on account of their appearance. For instance, the Glenboig bricks are among the most refractory firebricks made in this country, yet they are highly discoloured by spots of complex silicates.

Some analysts have endeavoured to calculate the composition of a fireclay brick from that of the clay of which it was made. Such a calculation can only be approximately correct, and occasionally it is seriously in error as the losses in burning are greater than anticipated.

Mineralogical Composition.

The mineralogical composition—sometimes termed the *proximate composition*—of a fireclay brick can only be estimated in a comparatively rough manner, as the greater part of the material is amorphous and cannot be positively identified with any definite mineral. The so-called “rational” calculations, based on a chemical analysis and assuming that all the potash and soda are present as felspar, any remaining alumina is present as clay, and any surplus silica is in the free state, are interesting and sometimes helpful, but they are at the best, merely ingenious guesses at the nature of the materials present and occasionally they are seriously misleading. In most cases, they are better avoided, except by those who are well trained in their use and limitations.

When rightly applied, the proximate composition of a brick shows the nature and proportion of the

impurities present in a clearer manner than the results of an ordinary chemical analysis, as the various minerals are expressed in terms of the actual substances present, and not as the equivalent oxides. Thus, it is easier for many people to appreciate the composition of a material stated to consist of—

Clay	82 per cent.
Chalk	11 "
Quartz	7 "
	<hr/>
	100.00

than if the results of its analysis are expressed as—

Silica	44.9 per cent.
Alumina	32.8 "
Calcium oxide	6.0 "
Carbon dioxide	5.0 "
Other oxides	0.7 "
Water	10.6 "
	<hr/>
	100.0

In order that the proximate or mineralogical composition shall be accurately expressed, it is necessary that the proportions of the various minerals actually present shall have been ascertained with a fair degree of accuracy. Otherwise, as previously explained, the results may be seriously misleading.

The identification and determination of the various minerals is a slow and tedious piece of work and can seldom be carried out completely, as some of the minerals are in the form of such minute particles that their identity cannot be recognized. This is

particularly the case with "burned clay" which forms by far the most important constituent of fireclay bricks.

Some of the more easily distinguishable minerals in fireclay bricks can be identified by means of a microscope, using the methods described in the text-books on petrology. The proportions of the greater part of the impurities in fireclay bricks cannot be definitely ascertained in this way, owing to their wide distribution and the indefinite characters which they possess. For this reason, the removal of impurities from fireclays is often extremely difficult.

One of the most important of the minerals which can be recognized in properly burned fireclay bricks is sillimanite, which contains 63 per cent of alumina and 37 per cent of silica. The crystals of sillimanite can easily be separated from the amorphous material by treating suitable sized fragments of the bricks with hydrofluoric acid; this dissolves the calcined clay, free silica and various silicates yet scarcely attacks the sillimanite, which is left behind in the form of minute lath-like crystals.

Sillimanite has a melting point of 1850° C. and is, therefore, highly refractory. The felted mass of crystals which it forms in firebricks is also particularly resistant to sudden changes in temperature. It is only formed at temperatures exceeding 1200° C. and its presence in considerable proportion is, therefore, an indication that fireclay bricks containing it have been well burned. It is entirely absent from seriously under-burned bricks.

Quartz is one of the other forms of free silica. It is usually present in fireclay bricks and can readily be identified by examining a section of the brick about one-thousandth of an inch thick under the microscope using polarized light. The quartz crystals are then clearly visible against an almost black background.

Other minerals present in fireclay bricks occur in such small proportions that they are outside the scope of this book. Readers who wish for further information should see any good book on petrology, or the author's work on *Refractory Materials: their Manufacture and Uses* (Griffin).

The proximate composition of fireclay bricks corresponds to an agglomeration of particles of "calcined clay,"* quartz, a little cristobalite (p. 35) and, in the best bricks, a notable proportion of felted crystals of sillimanite (p. 19). All these materials are united by a glassy or slag-like matrix composed of calcium, magnesium, sodium and potassium silicates, aluminates and alumino-silicates with a complex iron silicate resembling fayalite. The glassy matrix increases in quantity and fluidity as the temperature of the bricks rises above 1300° C., and it gradually attacks the more refractory quartz and "calcined clay," and dissolves them. If the heating is prolonged sufficiently whilst the increase in temperature continues, the whole of the material present will be converted into a viscous molten glass or slag, but under normal conditions so extensive a change never occurs. The reactions which result in the formation of the glass are arrested by the

* The precise nature of calcined clay is not certainly known.

cooling of the furnace or by other means before they are completed, but in all well-burned fireclay bricks a variable, yet easily recognized, proportion of the glassy matrix is present and it gradually increases in amount the longer the bricks are used at a high temperature.

Crushing Strength.

When fireclay bricks are subjected to a compressive stress sufficient to crush them they crack and then fall to pieces. If well-made and of good material they will withstand a pressure of at least 1,800 lb. per sq. in. applied to one end of the brick, when the latter is placed with its long side in a vertical position. The crushing strength is seriously reduced by flaws in the texture of the brick and by applying the pressure to the heated brick (see next section). As most firebricks have ample strength when cold, there is very little to be gained by determining the crushing strength of cold bricks, but their resistance to pressure when heated is very important.

Effect of Pressure at High Temperatures.

When fireclay bricks are heated and at the same time subjected to a load or pressure, the temperature at which they lose their shape is much lower than when they are quite free. Thus, if they are subjected to a downward pressure of 50 lb. per sq. in., even the best fireclay bricks will lose their shape at a temperature of about 1350° C., whilst those made of less refractory clay will be distorted at a

much lower temperature. The American Bureau of Standards has, therefore, specified that first-class or No. 1 grade fireclay bricks shall not show any serious deformation when heated 1350°C . under a pressure of 30 lb. per sq. in., and that second-class or No. 2 grade fireclay bricks shall not show any serious deformation at 1350°C . under a pressure of 25 lb. per sq. in.

Shrinkage on Reheating.

When fireclay bricks are exposed in use to a higher temperature than that at which they have been heated by the manufacturer, or when such bricks are subjected to prolonged heating at almost any temperature above 1300°C ., they tend to shrink or contract. In some cases, the effect of this shrinkage is very serious and may cause the collapse of the structures in which the bricks are used. This defect may be largely avoided by using only bricks which have been burned at a sufficiently high temperature, though this is not sufficient in some cases, such as roofs or crowns of furnaces which are continuously maintained at a temperature above 1400°C . For such structures the bricks employed should be made of silica or some other material which does not shrink in use. For all other purposes it is usually sufficient that the bricks shall not shrink more than $\frac{1}{16}$ in. when reheated to 1400°C ., and maintained at that temperature for two hours.

The Standard Specification of the Institution of Gas Engineers requires that No. 1 grade fireclay bricks shall

not shrink more than 1 per cent, and No. 2 grade fireclay bricks not more than 1.25 per cent when heated to Cone 14 (1410° C.) for two hours and maintained at that temperature throughout the testing period."

Effect of Changes in Temperature.

Fireclay bricks are remarkably insensitive to sudden changes in temperature, especially if they are sufficiently porous. This constitutes one of the valuable characteristics in which they are greatly superior to silica and magnesia bricks. The only refractory bricks which are less sensitive than fireclay bricks to violent changes in temperature are those made of kieselguhr (which are usually less refractory) and bricks containing an exceptionally large proportion of felted sillimanite crystals; the latter are not, at present, on the market and are very costly to produce.

Other Properties of Fireclay Bricks.

Among the other properties of importance possessed by good fireclay bricks are the emission of a clear ringing note when struck, their hardness and resistance to abrasion, their toughness and resistance to shocks and blows, and their remarkably low power of conducting heat and electricity. Their resistance to heat and their chief usefulness in industry are largely due to their low thermal conductivity which enables great heat to be developed and very high temperatures attained in furnaces and other structures built of fireclay bricks. The specific heat of fireclay bricks is also very low but rises at

higher temperatures. The resistance of such bricks to acids is also important in some industries.

Summary.

For most purposes where firebricks are required those made of fireclay are the most generally suitable. Bricks made of other materials have special properties which are superior for certain purposes, but for general use, well-made fireclay bricks can usually be relied upon. For further particulars respecting their uses see Chapter VII.

GROG BRICKS

For many years in Germany and Scandinavia, and to a smaller extent in other countries, furnace linings have been constructed of *grog* or *chamotte bricks*. These bricks are made chiefly of fireclay which has previously been heated to a temperature of at least 1200° C., after which it is examined and the obvious impurities removed. The remainder of the material termed "grog" or "chamotte" is then ground to a coarse powder, mixed with clay or other suitable binding agent and made into bricks.

The chemical composition of *grog* bricks does not differ greatly from that of fireclay bricks made direct from raw clay, though the previous calcination of the clay in order to form *grog* causes the volatilization of some of the soda and potash, and thus tends to produce a slightly more refractory material.

The chief advantages possessed by *grog* bricks are their greater constancy of volume when reheated and their greater resistance to abrasion and

corrosion. These advantages are all due to the grog having been calcined at a sufficiently high temperature before it was made into bricks, and to the facilities offered for making grog bricks of particles of fully-burned material of carefully selected sizes. This latter is quite impossible when raw fireclay is used as most of the particles in it are extremely small and are, to that extent, inferior to the large particles obtainable when grog is used.

For these reasons, grog bricks are superior to fireclay bricks in refractoriness, texture, and durability. They shrink less in use, yet have all the other desirable properties of fireclay bricks.

On the other hand, they cost more to produce because of the preliminary calcination of the clay needed to produce the grog. Apart from their texture they are difficult to distinguish from fireclay bricks and the same specifications are equally applicable to both.

Some grog bricks have the disadvantage of being rather more porous than bricks made wholly from raw fireclay and may therefore be more rapidly penetrated by slags, etc. Some also have rather less crushing strength, but this only occurs when the binding clay is deficient in quantity or has a short range of vitrification.

Careful comparisons between the behaviour of grog bricks and that of bricks made solely of fireclay have always shown the practical superiority and greater durability of grog bricks, but they are only used to a limited extent on account of their greater cost.

Some manufacturers add a small proportion of grog (in the form of broken firebricks) to the clay used in the manufacture of fireclay bricks. Such an addition does little more than slightly reduce the shrinkage. There is no control of the size of the particles of brick which are mixed with the clay, and there is a tendency to grind it too fine. The term "grog bricks" should not be applied to firebricks containing less than 50 per cent of grog; the best grog bricks contain 80 to 85 per cent of this material and 15 to 20 per cent of a highly plastic clay.

SILLIMANITE BRICKS

Recently, firebricks have been made from natural sillimanite and also from an artificially prepared material of similar nature. They are too "new" for a definite opinion to be expressed as to their commercial value, but the experiments already made with them suggest that they will be superior to grog bricks. They are, at present, chiefly used in the glass-making industry (*see also* p. 41).

FLINT-CLAY BRICKS

Flint-clay bricks are largely made in America from a very hard refractory clay which does not occur in this country. They are similar to grog bricks, the flint-clay being used instead of grog; its particles are cemented together by a plastic binding clay. Flint-clay bricks contain no "flints."

SILICA BRICKS

SILICA BRICKS

Silica bricks, as their name implies, are composed chiefly of silica and are usually made of quartz or quartzite rocks, pebbles of sands. These materials are crushed, if necessary, mixed with either clay or lime as a binding agent and water, and are then moulded or pressed into bricks which are afterwards dried and then burned at a temperature of from 1300°C . to 1500°C . Silica bricks are extensively used in the construction of furnaces and are employed for the same purposes as fireclay bricks. They differ from the latter in expanding instead of contracting when in use, in being much more sensitive to sudden changes in temperature and in several other respects. Silica bricks (especially those known as "Ganister bricks") are particularly used in steel-making furnaces and in coke-ovens, but their other uses are as varied as those of fireclay bricks.

Colour.

The colour of silica bricks is a pale yellow or buff, varying in parts to dark brown and accompanied by spots of black slag-like material formed by the combination of iron compounds and silica in the brick. When examined under a magnifying glass, the bricks are seen to be composed chiefly of colourless transparent grains of crystalline silica, together with a small proportion of opaque and dark-coloured material representing the impurities in the bricks (see p. 33).

Shape.

Silica bricks are similar in shape to all other firebricks, though the thick bricks are not so common as thinner ones. The surfaces of the bricks should be reasonably smooth, free from obvious flaws, "winding" and other irregularities. Accuracy of shape is equally as important as in fireclay bricks (p. 6). Silica bricks tend to twist or warp in the course of manufacture so that it is important, when purchasing them, to fix a limit (such as $\frac{1}{16}$ in. per 9 in. brick) for the maximum amount of distortion which will be accepted.

Bricks having crazed, cracked, or fractured faces should not be used for important work.

Dimensions.

Silica bricks are usually 9 in. \times $4\frac{1}{2}$ in. \times 3 in., $2\frac{1}{2}$ in., or 2 in. They should not vary from these dimensions by more than $1\frac{1}{2}$ per cent in the length or $2\frac{1}{2}$ per cent in width or thickness, these being the limits imposed by the Standard Specification of the Institution of Gas Engineers. In the United States the maximum variation usually permitted in specifications is $\frac{1}{16}$ in. in the length of the brick, or 0.7 per cent. For accurate work in important furnaces, coke-ovens, etc., it is customary in the United States to finish silica bricks accurately to size by grinding them just prior to delivery. Consequently, a greater accuracy is obtained than in this country where the surface of the bricks is not destroyed by such treatment.

SILICA BRICKS

Texture.

Most English silica bricks are of much coarser texture than fireclay bricks and can be seen, under even a magnifying glass, to consist of grains of silica united together by a glassy matrix. These grains vary in size from $\frac{1}{4}$ in. to "dust," the majority being about $\frac{1}{16}$ in. (0.025 in.) diameter. Where possible the largest sized particles should not be more than $\frac{1}{4}$ in. (0.125 in.) diameter. In perfectly made silica bricks the grains are so arranged as to form, with the matrix, an impermeable mass, but few silica bricks attain to this ideal, and most of them contain a considerable proportion of interstices between the solid particles (see *Porosity*, p. 30).

The texture of silica bricks has an important influence on their resistance to abrasion and corrosion. If the particles are too large they tend to leave excessively large hollows when they are torn out by abrasion, or when they fall out as a result of the removal of the matrix by corrosion. Excessively fine particles, on the contrary, offer too little resistance to slags and other solvents and in this way reduce the durability of the bricks, though minute particles tend to produce bricks of much greater mechanical strength than those composed chiefly of larger particles. Silica bricks are more affected than fireclay bricks by corrosive slags and fine dust. They are rapidly attacked by basic materials, with the formation of readily-fusible compounds. Thus, a silica brick placed on a magnesite brick and the two being heated in a furnace will result in serious damage to both bricks.

Silica bricks have also a very low resistance to abrasion and, therefore, should not be exposed more than necessary to this action.

The most important effect of small particles, however, is the rapidity with which they facilitate the conversion of quartz to tridymite and cristobalite respectively. This change is essential to the production of silica bricks of the highest quality for, in proportion to the extent to which it occurs, the bricks remain more nearly constant in volume when heated.

The form in which crystalline silica usually occurs in nature is that of quartz, and when this is heated to a sufficiently high temperature (at least $870^{\circ}\text{C}.$) for a sufficient length of time, it is converted into cristobalite or tridymite according to the conditions under which the heating occurs. The changes which quartz undergoes on heating and cooling are very complex, several varieties of quartz, tridymite and cristobalite being formed.* The chief feature of these changes is an increase in the volume of the silica which reveals itself in an expansion of the bricks during their burning in the course of manufacture. If the conversion of quartz into tridymite or cristobalite is not complete, the bricks will continue to expand when in use (see *Expansion*, p. 37), often with disastrous consequences to the structure in which they are employed.

Porosity.

Most silica bricks have about the same porosity

* For a detailed consideration of this subject see *Refractory Materials in Their Manufacture and Uses*, by A. B. Searles.

as fireclay bricks, but those produced by different firms vary so greatly that no general statement on the matter is of much value. When drawing up a specification it is usually satisfactory to demand at least 12 per cent by volume or 6 per cent by weight, as for fireclay bricks (p. 12).

Volume-Weight and Apparent Density.

This varies very greatly so that no definite figure can be given. It is, however, usually rather less than that of fireclay bricks (p. 12).

True Specific Gravity.

One of the most convenient indications of the extent to which silica bricks have been properly burned, and of the proportion of the quartz converted into tridymite or cristobalite (p. 30), is the true specific gravity of the bricks. This is estimated by grinding a portion of a brick to a fine powder and determining its specific gravity.

Quartz	has a specific gravity of	2.653
Tridymite	" " " "	2.323
Cristobalite	" " " "	2.318

The true specific gravity of the material is approximately proportional to the percentage of unaltered quartz present. Thus, a silica brick with a specific gravity of 2.46 can be relied upon to contain at least 40 per cent of unaltered quartz.*

* The percentage of unaltered quartz may be found by deducting 2.32 from the specific gravity of the sample and multiplying the result by 300.

Refractoriness.

Silica bricks made of the best materials have a refractoriness corresponding to Cones 34 or 35, but the Specification of the Institute of Gas Engineers (which is commonly accepted as the standard in this country) only demands a refractoriness equal to Cone 32 for bricks containing at least 92 per cent of silica or to Cone 29 for "siliceous" bricks containing from 80 to 92 per cent of silica.

As silica cannot be made into bricks without the presence of a binding agent, present as a natural impurity or added purposely, silica bricks are always slightly less refractory than the silica of which they are chiefly composed. The refractoriness is determined as described on p. 2. For the effect of pressure on the refractoriness of silica bricks. (see p. 36).

Melting Point or Fusibility.

Very minute particles of silica melt at 1470°C. , and larger particles at about 1600°C. , whilst pieces of $\frac{1}{4}$ in. or more in diameter do not show any signs of fusion below 1750°C. , except on very prolonged heating. This difference is due to the low thermal conductivity of silica which makes it very difficult for heat to penetrate a mass of the material. For this reason, silica bricks can be used in furnaces, the contents of which are at a temperature from 200° to 250°C. above the true melting point of silica. If a silica brick be heated on all sides for a sufficiently long time its fusibility approaches its

true melting point, but the circumstances in which silica bricks are usually employed do not permit complete fusion to occur.

Chemical Composition.

A perfectly pure silica brick could only exist if it were made by casting fused quartz or by sintering together particles of silica without the use of a binder. When bricks are made, as is the customary manner, by compressing small particles of wet silica in a mould or press, it is necessary to have a binding agent present in the bricks or they would fall to pieces when heated. The two binding agents of chief importance are : (a) plastic, refractory clay ; and (b) lime. When clay is used a considerable proportion is required, as described later (see *Semi-silica Bricks*, p. 39), but $1\frac{1}{2}$ to 2 per cent of lime is equally effective and has a far less effect on the chemical composition of the bricks. Silica bricks bonded with lime have a chemical composition corresponding very closely to that of the silica rock of which they are made, plus $1\frac{1}{2}$ to 2 per cent of lime added as a binding agent. The figures shown in Table II on page 34 are typical.

The maximum proportion of "impurities" permissible is not usually specified, though it is customary to require that there shall not be more than 2 (or in some cases, 3) per cent of lime. The most conspicuous impurity is the complex iron silicate which produces the dark brown patches and black spots in silica bricks, and originates in the iron pyrites (ferrie sulphide) present in the raw silica. In a

TABLE II.—ANALYSES OF SILICA BRICKS.*

	Yorkshire.	Durham.	N. Wales.	Glanister.
	%	%	%	%
Silica . . .	94.9	98.9	95.74	96.88
Alumina . . .	1.52	0.45	1.06	0.80
Iron Oxide . . .	1.34	1.12	0.54	0.60
Lime . . .	1.90	0.90	1.32	1.45
Magnesia . . .	Trace	Trace	0.28	0.02
Potash { . . .	0.55	0.39	0.87	0.25
Soda { . . .				

* "Special Report XVI on the Mineral Resources of Great Britain," p. 55.

chemical analysis the iron in this compound is included in the ferric oxide or iron oxide and most specifications and descriptions of silica bricks deal with it as though the iron were all in the form of oxide. The limits of composition of silica bricks are usually from 95 to 98 per cent of silica; 0.5 to 2.75 per cent of alumina; 0.3 to 1.25 per cent of iron oxide; and 0.2 to 2.1 (usually 1 to 1.5) per cent of lime. The percentage of iron oxide should be sufficiently low not to prove detrimental to the bricks, above 2 per cent being usually considered excessive.

Mineralogical Composition.

The most important minerals present in silica bricks are quartz, tridymite and cristobalite with a much smaller percentage of wollastonite in the form of a complex glassy calcium silicate (silicate of lime).

The quartz, tridymite and cristobalite are three

different forms of pure crystalline silica readily distinguished under the microscope by their different optical properties and particularly by their respective *refractive indices*, which are: quartz, 1.55; tridymite, 1.477; and cristobalite, 1.484.

Quartz is usually observed as fragments of hexagonal crystals, readily visible in polarized light; tridymite as needle-shaped crystals; and cristobalite as minute plates. As explained on p. 30, the best silica bricks are those in which the largest proportion of quartz has been converted into one or both of the other forms which are more stable at high temperatures, this conversion taking place most rapidly in bricks composed of minute particles and with a moderately large proportion of molten or glassy silicate. As it is undesirable (on account of its effect on the refractoriness) for silica bricks to contain more than $2\frac{1}{2}$ or 3 per cent of lime (and usually these figures are excessive), the total proportion of fusible silicate in a first-class silica brick cannot exceed 6.2 per cent.

The other minerals present, with the possible exception of iron silicate (p. 33), are usually unimportant.

Proximate Composition.

Silica bricks may be regarded as composed of an agglomeration of particles of silica (in the forms of quartz, tridymite and some cristobalite) united by a glassy matrix containing calcium, magnesium, sodium and potassium silicates, and a complex iron silicate. If clay be present, the matrix may also

contain aluminates and alumino-silicates of the metals mentioned. A few adventitious particles of other minerals are usually present, but are of no serious significance.

The effect of prolonged heating on this agglomerate is similar to that on fireclay bricks (p. 20) except that, the particles of silica being coarser, they do not undergo corrosion and fusion so rapidly, until their critical temperature (about 1470° C.) is reached, after which they dissolve fairly rapidly in the glassy mixture of silicates.

Crushing Strength.

Silica bricks owe their strength principally to the complex glassy silicate which binds the particles of silica together. When cold, the normal crushing strength should not be less than 1,800 lb. per sq. in., and except in the case of obviously underfired bricks there is little reason for determining the crushing strength of cold silica bricks.

Effect of Pressure at High Temperatures.

When silica bricks are heated under a pressure of 50 lb. per sq. in., they retain their shape until a temperature of about 1470° C. is reached when they collapse suddenly. In this respect they differ from fireclay bricks which yield gradually under the same conditions and so give a better warning of their impending failure. On the other hand, the fact that silica bricks can withstand a somewhat higher temperature when loaded is often an advantage in furnace construction, etc. (see *Reheating*, p. 37).

Expansion on Reheating

Unless they have been particularly well burned silica bricks will expand when reheated to a sufficiently high temperature. This expansion is due to the conversion of some of the unaltered quartz into one of the other forms of silica (p. 30) and it is liable to cause serious damage to the structure in which the bricks are used.

The Standard Specification of the Institution of Gas Engineers only imposes a mild test, namely, that when a piece of brick $4\frac{1}{2}$ in. square is heated for 2 hours at a temperature corresponding to Cone 14 and then cooled, it shall not have expanded more than 0.75 per cent of its length. In the corresponding specification of the American Gas Institute it is stated that the brick "when reheated under a load of 25 lb. per sq. in. to 1500° C. and maintained at this temperature for $1\frac{1}{2}$ hours" (and then allowed to cool during not less than 10 hours) "shall not show a permanent swelling above 1 per cent or any vitrification or other deterioration."

Sensitiveness to Temperature Changes.

Silica bricks are very liable to spall if heated or cooled suddenly, or if a current of air is allowed to play on the hot bricks. Indeed, this sensitiveness to sudden changes in temperature is one of their greatest drawbacks. It appears to be an inherent property and though it is less noticeable in bricks with a small proportion of unaltered quartz, even the best silica bricks show considerable sensitiveness, particularly on cooling.

On account of their tendency to spall and flake silica bricks should not be used where they are likely to be exposed to sudden changes in temperature. In furnaces, etc., where they are maintained at a fairly high temperature constantly, this objection does not apply and silica bricks are often used with advantage.

Other Properties of Silica Bricks.

Among other properties of importance possessed by silica bricks are the clear "ring" they emit when struck, and their hardness and resistance to blows. Their power of conducting heat is appreciably greater than that of fireclay bricks (p. 23), though sufficiently low to make them of great value in the construction of furnace linings, etc. They are regarded as superior to fireclay bricks for the construction of coke-ovens, as their slightly higher thermal conductivity enables the coking of the coal to be effected more rapidly and with slightly less expenditure of fuel. The specific heat of silica bricks is slightly higher than that of fireclay bricks.

Summary.

Silica bricks are extensively used for the roofs of furnaces and for other parts of these structures where the temperature is fairly constant and they are not unduly exposed to corrosion or abrasion. As they tend to expand in use, arches and roofs made of silica bricks are less liable to collapse than those made of fireclay bricks (which tend to shrink).

The chief disadvantage of silica bricks is their tendency to spall or flake when suddenly heated or cooled. For further particulars respecting their uses see Chapter VII

SEMI-SILICA BRICKS

Bricks made of a mixture of silica and clay are known as "semi-silica" or "ganister" bricks. When the proportion of clay is very small, and the wet material is self-binding, it is commonly known as "ganister" (p. 92), and the bricks as "ganister bricks." Bricks containing a larger percentage of clay (though not necessarily as much as 50 per cent) are usually termed "semi-silica bricks"; they may be made from natural mixtures or from those prepared artificially, such mixtures being ground, wetted and moulded or pressed into bricks which are then dried and burned at a high temperature.

In their general properties, ganister bricks resemble silica bricks bonded with lime (p. 33), whilst semi-silica bricks are intermediate between fireclay and silica bricks, and have the advantage of being almost constant in volume when reheated. This is due to the effect of the shrinkage of the clay being neutralized by the expansion of the silica. The addition of silica to a refractory clay often reduces its refractoriness considerably, though if the clay is of low refractoriness the addition of silica may raise its softening point.

Semi-silica bricks are also capable of bearing at high temperatures a load which is greater than that

which fireclay bricks can support, though less than that which pure silica bricks can carry.

Semi-silica bricks are attacked by slags, etc., in a manner similar to silica bricks.

Ganister bricks are extensively employed in the furnaces used for making steel, whilst semi-silica bricks are chiefly employed where constancy of volume is the first consideration.*

ASBESTOS BRICKS

Refractory bricks are sometimes made from a mixture of fireclay and asbestos, in the proportions of 2 : 1. Sawdust is also added, when it is desired to make very light, porous bricks of higher heat-insulating power than the denser bricks. Such light bricks are very useful for partitions, etc. but they are not resistant to slags and abrasion from which they must be suitably protected.

KIESELGUHR BRICKS

Light refractory bricks are also made by mixing kieselguhr or diatomaceous earth (a natural deposit of the siliceous skeletons of minute plants) with fireclay. These bricks are extremely light and porous, and fairly refractory so that they are especially useful where these qualities are required, but they are readily attacked by slags and easily abraded so that they cannot be used in furnace linings without protection.

* For further details see the author's larger work, *Refractory Materials: their Manufacture and Uses* (Griffin).

HIGHLY ALUMINOUS BRICKS

HIGHLY ALUMINOUS BRICKS

Fireclay bricks and grog bricks may contain 35 per cent of alumina, but for more highly aluminous bricks white bauxite or some other form of alumina must be used. As alumina has a melting point of 2000°C . it is more refractory than fireclay, but being quite devoid of plasticity it requires the addition of a binding agent, fireclay being usually employed for this purpose. One firm in this country has, for some time, manufactured highly aluminous bricks from an unusual material found in Ayrshire, Scotland.

Bricks made of fireclay and bauxite are not so refractory as bauxite bricks which do not contain a clay bond, but they are stronger.

Corundum Bricks.

Owing to the exceptional hardness and refractoriness of crystalline alumina (e.g. artificial corundum), bricks made of this material should be extremely refractory and resistant both to abrasion and corrosion. Unfortunately, the cost of corundum and the necessity of employing a binding agent inferior to corundum in refractoriness, have prevented these bricks from being used in large numbers.

Sillimanite Bricks.

The most satisfactory bricks made from a mixture of clay and alumina, are those in which the proportions of alumina and silica are the same as in sillimanite (p. 19), the natural brick being burned at

such a temperature as to produce as high a proportion as possible of this mineral. Bricks largely composed of crystalline sillimanite have now been placed on the market; other bricks offered as sillimanite are made in the United States by fusing clay with alumina at a temperature of about 1400° C., using a blast of air under a pressure of 3 to 6 lb. per sq. in. The resulting "sillimanite" is crushed to a suitable size and mixed with highly plastic binding clay to cement the non-plastic particles of "sillimanite" together. It is claimed that such bricks have all the advantages to be obtained by the formation of crystalline sillimanite by burning fireclay bricks at a very high temperature. They are extremely refractory, constant in volume, capable of carrying heavy loads at high temperatures, and very resistant to corrosion. In other properties they resemble fireclay bricks but contain a much larger proportion of alumina. At present, however, the cost of such bricks is almost prohibitive (*see also* p. 26).

When properly prepared highly aluminous bricks are very refractory and resistant to corrosion.*

MAGNESIA BRICKS

Bricks made of crude, dead-burned† magnesite‡ are extensively used for the construction of basic linings

* For further information *see* p. 26; also the author's *Refractory Materials; their Manufacture and Uses* (Griffin).

† For an explanation of this term *see* p. 104.

‡ As they are made from magnesite they are commonly termed *magnesite* bricks, but they are actually composed of *magnesia*, the change from the carbonate to the oxide being effected by burning the magnesite prior to making it into bricks.

in furnaces employed in the manufacture of steel by the "basic" process. Their chief characteristics are their great refractoriness and their resistance to slags of a basic nature. Most of them are, like silica bricks, extremely sensitive to sudden changes in temperature.

Colour.

Most magnesia bricks contain an appreciable proportion of iron oxide which is the cause of their reddish colour, but magnesia bricks which are exceptionally low in iron are a dirty white. If the bricks have been heated under highly reducing conditions they may be dirty grey, dark brown, or almost black.

Texture.

Magnesia bricks should have a regular texture, the particles being all less than $\frac{1}{8}$ in. diameter and so graded as to fill the interstices without any unnecessary voids. If the particles are unduly small they yield too readily to the corrosive action of silica and siliceous slags, but particles which are too coarse tend to produce bricks which are too weak and excessively porous. The particles are united by a glassy matrix, usually dark in colour as a result of the iron present.

The effect of acid materials (including silica and siliceous slags) is highly corrosive, and magnesia bricks offer a poor resistance to such substances. On the other hand, magnesia bricks are not affected

by the basic slags which are so destructive to fireclay and silica bricks.

If made of suitable and well-graded materials, magnesia bricks are highly resistant to abrasion, but the particles should not be too coarse or, the gaps left when they fall out of the bricks are serious.

Porosity.

Magnesia bricks are usually fairly porous, 20 per cent porosity being by no means uncommon. The use of temporary binders tends to increase the porosity; where the bricks are required to resist the action of slags a low porosity is desirable, but for resisting sudden changes of temperature a more open brick is required.

The *volume-weight or apparent density* of magnesia bricks is very high.

Specific Gravity.

The true specific gravity (i.e. the specific gravity of the finely-powdered material) of magnesia bricks is of great importance as it affords an excellent indication as to the extent to which the burning has fulfilled its purpose in converting the magnesite into the mineral periclase. Magnesite has a specific gravity of 3.02, amorphous magnesia 3.0 to 3.2, and periclase 3.4 to 3.6. As it is of the greatest importance that magnesia bricks should contain as large a proportion of periclase as possible, it is usually wise to discard magnesia bricks with a true specific gravity of less than 3.3.

Refractoriness.

Pure magnesia has a melting point of 2500°C. , but most magnesia bricks have a refractoriness corresponding to Cone 42 (2000°C.).

Chemical Composition.

Magnesia bricks have a chemical composition very similar to that of the dead-burned material of which they are made, though the composition is affected by the binding agent used, namely, caustic magnesia, clay, colloidal silica or a temporary bond such as tar, cellulose lye, etc. The figures shown in Table III are typical—

TABLE III.—ANALYSES OF MAGNESIA BRICKS.*

	Hungarian.	Styrian.	Grecian.
	%	%	%
Silica	0.35	3.10	2.16
Alumina and Iron Oxide	6.05	6.64	0.72
Lime	2.10	3.76	4.20
Magnesia	91.52	86.50	93.93

* Eckel, *Cements, Limes, and Plasters* (Chapman & Hall).

Mineralogical Composition.

When properly burned, magnesia bricks should contain a large percentage of periclase—a crystalline form of magnesia, stable at high temperatures, which is formed by heating magnesium carbonate or magnesia to a temperature of 1450°C. to 1700°C. , particularly in the presence of a flux such as iron oxide. Unless they are burned at a higher

temperature than is customary in this country, the proportion of periclase formed is only small, with the result that the bricks shrink greatly and are unduly sensitive to sudden changes in temperature; in this respect they resemble silica bricks.

In a very thin section of a magnesia brick the vitrified material ("dead-burned magnesia") appears under the microscope as a dark coloured glassy mass, but periclase, when present, takes the form of rounded grains set in a glassy matrix.

The other minerals present in magnesia bricks are chiefly glassy silicates and spinels, which are formed by the action of various metallic oxides on any silica present and on each other.

Proximate Composition.

Magnesia bricks are composed chiefly of a partially vitrified mass of crude magnesia containing a variable proportion of crystalline periclase, the particles being united by a glassy matrix composed of sundry silicates and spinels. When such bricks are subjected to a prolonged heating at 1500°C . or above, the proportion of periclase increases more or less slowly and at the same time the amount of magnesia which is dissolved in the glassy matrix also increases. As magnesia exerts a toughening influence on glasses and slags, increasing their viscosity very considerably, the matrix in magnesia bricks does not attack the unaltered particles so rapidly as in fireclay bricks or silica bricks. For this reason, magnesia bricks are often more refractory in use than a laboratory test of their refractoriness suggests.

MAGNESIA BRICKS

Crushing Strength.

When cold, magnesia bricks have a crushing strength rather higher than that of fireclay bricks. Their strength when cold may be increased by the addition of a small percentage of iron oxide, but this decreases their strength at high temperatures.

Effect of Pressure at High Temperatures.

When magnesia bricks are heated under a pressure of 50 lb. per sq. in., they retain their shape without distortion until a temperature of about 1550° C. is reached, when they suddenly collapse. In this respect they resemble silica bricks (p. 36), rather than fireclay bricks (p. 21), which are gradually distorted as the temperature rises above 1300° C.

Shrinkage on Reheating.

Magnesia bricks, unless exceptionally well-burned, shrink when in use, the contraction being roughly proportional to the extent to which they have been under-fired. This shrinkage is very noticeable if the magnesia, of which the bricks are made, has not been fully dead-burned. The shrinkage of bricks made of lightly-burned magnesia is so great that it is almost impossible to prevent them from twisting and cracking when they are reheated. On the other hand, bricks made from fully dead-burned material do not shrink in use more than the best fireclay bricks. The best qualities of magnesia bricks should not have more than 5 per cent linear (15 per cent cubical) contraction when in use, and a lower shrinkage than this is desirable.

Sensitivity to Temperature Changes.

Most magnesia bricks are highly sensitive to sudden changes in temperature and they spall or flake readily when cooled suddenly. This appears to be due largely to the instability of the magnesia, as bricks containing a larger proportion of periclase are far less sensitive. This tendency to spall or flake is a very serious drawback to magnesia bricks, and prohibits their use in some cases where otherwise they would be invaluable; it limits their usefulness to furnaces, etc., in which no sudden changes in temperature are likely to occur. This difficulty is, to some extent, overcome by the use of iron cases to contain the bricks.

Other Properties of Magnesia Bricks.

Among the properties of magnesia bricks of lesser importance are their hardness, their metallic "ring" when struck and their great "weight." They are readily attacked by acids and even by water and steam, but can withstand damp air for a moderate length of time. They should never be exposed to the weather, but should be kept in a dry and, preferably, in a warm building.

Summary.

Magnesia bricks are invaluable where bricks of a basic character are required. They are costly to produce on account of the very high temperature needed to convert the magnesia into periclase.

They are very sensitive to sudden changes in temperature.*

DOLOMITE BRICKS

Bricks made of a double carbonate of magnesia and lime (dolomite) have been used in some steel furnaces with indifferent success, but crushed dolomite has long been used in lining furnaces for the manufacture of steel by the basic process. Dolomite is inferior to dead-burned magnesite as the lime is objectionable, but dolomite is so abundant and relatively so cheap that it will continue to be used for this purpose.*

LIME BRICKS

Many attempts have been made to produce good bricks from lime, but without success, as the material is too easily disintegrated by moisture, and forms too fluid a matrix with any silica or clay added as a binding agent. Lime bricks also have an excessive shrinkage, low mechanical strength, and for other reasons are not very durable.

CHROMITE BRICKS

Firebricks made of chromite are used to a limited extent in the neutral courses between acid (fireclay or silica) and basic (magnesia) bricks. The ore is ground and mixed with a suitable quantity of bond (such as clay, lime, bauxite, magnesia, chromium salts or alkali salts) and water. The

* For further particulars see the author's larger work: *Refractory Materials; their Manufacture and Uses.*

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paste is shaped by hand in iron moulds and the bricks are dried and finally burned at a temperature of at least 1460°C . (Cone 16).

"In some chromite bricks, tar is used as a bond, in which case the dry materials are mixed by hand, with melted tar, on a floor and moulded whilst the mass is still hot and plastic.

Colour.

Chromite bricks are dark brown in colour, on account of the iron oxide present.

Texture.

Little attention is usually paid to the texture of chromite bricks, but it should be fine rather than coarse so as to resist abrasion. Chromite is so inert that no special precautions need usually be taken to resist corrosion.

Porosity.

Chromite bricks are usually of about the same porosity as fireclay bricks.

Specific Gravity.

Chromite bricks vary in specific gravity on account of the variations due to the temperature of calcination, and to the impurities in the chromite ore used.

Refractoriness.

The refractoriness of chromite bricks corresponds to Cones 31 to 38, but varies considerably according to the percentage of chromium oxide in the ore.

used. The *melting point* of pure chromium oxide is about 2000° C.

Chemical Composition.

Chromite bricks correspond very closely in composition to the ore of which they are made (p. 108). The chief impurity is iron oxide, as pure chromite is too valuable to be used for brickmaking. For this reason, chromite bricks are not made with the same regard to quality as are the best magnesia, silica, and fireclay bricks, but this is not usually of much importance, as even a comparatively low grade chrome ore will produce bricks which are quite satisfactory in use.

Crushing Strength.

Chromite bricks are not subjected to great pressures so that tests of their crushing strength are seldom of importance. Typical bricks will withstand a pressure of from 180 to 360 tons per sq. ft. (2,800 to 5,600 lb. per sq. in.).

Effect of Pressure at High Temperatures.

The temperature at which chromite bricks collapse when under a pressure of 50 lb. per sq. in., has only been determined on a very small number of bricks so that no very reliable figure is obtainable. The chromite bricks tested failed suddenly at 1450° C.

Shrinkage on Reheating.

* Chromite bricks shrink slightly when in use, but this is not serious if they have been properly burned in the course of manufacture.

Sensitivity to Temperature Changes.

Chromite bricks are not particularly sensitive to sudden changes in temperature.

IRON ORE BRICKS

Iron ore bricks are somewhat similar to chromite bricks of very low grade and are made by mixing iron ore with milk of lime, the same process being used as for silica bricks. Iron ore bricks are of poor quality as regards refractoriness and are useless in a reducing atmosphere.

TITANIC OXIDE BRICKS

Titanic oxide bricks are made by mixing crushed ilmenite or titanic iron ore with lime and water, and proceeding as in the manufacture of silica bricks. They are satisfactory acid refractory materials, but their cost is usually prohibitive.

CARBON BRICKS

Bricks made of graphite or coke are used in various metallurgical furnaces, especially in the boxes of blast furnaces. They are made by mixing crushed graphite or coke with tar, moulding the mixture in iron boxes, and then baking the boxes with their contents at a temperature just sufficient to char the tar.

Texture.

The texture of carbon bricks depends almost wholly on the graphite or coke used, the former

producing bricks of a flaky texture, whilst those made of coke are granular.

Corrosion and Abrasion.

Carbon bricks are highly resistant to corrosion but only moderately so to abrasion.

Refractoriness.

The melting point of carbon is much higher than the temperature attainable in the hottest industrial furnaces, so that carbon bricks are the most refractory. Unfortunately, they gradually burn away when heated in a current of air and so are not very durable.

Chemical Composition.

Carbon bricks are composed almost wholly of carbon, with a small proportion of hydrocarbons and a variable amount of mineral matter or "ash." The proportions of these minor constituents is very variable. The total amount of ash should not exceed 14 per cent.

Crushing Strength.

Carbon bricks are incapable of withstanding much pressure, but the crushing strength, when cold, should not be less than 1,000 lb. per sq. in.

Shrinkage on Reheating.

Most carbon bricks are constant in volume, when reheated in the absence of air. Under ordinary conditions they slowly burn away and thus become smaller and smaller.

Sensitiveness to Temperature Changes.

Carbon bricks are not sensitive to changes in temperature.

CARBIDE BRICKS

Artificial compounds of silicon and carbon, with or without oxygen, known by various names, such as carborundum, crystolon, silfrax, silundum, siloxicon, etc., are used for the manufacture of refractory bricks, by mixing them with a suitable bond (such as clay, lime, water-glass, or a temporary bond, such as dextrin) moulding, drying and finally burning the bricks at from $1400^{\circ}\text{C}.$ to $2000^{\circ}\text{C}.$

Colour.

Carbide bricks vary in colour according to the particular carbide present, but are usually dark grey, with a green lustre.

Specific Gravity.

The true specific gravity of pure carborundum is from 3.17 to 3.21. Other carbides and carboxides differ slightly according to their nature.

Refractoriness.

The refractoriness of carbide bricks is very high but varies according to the bond. Pure carborundum melts at a temperature of about $2500^{\circ}\text{C}.$, but begins to dissociate on prolonged heating at $1600^{\circ}\text{C}.$ or possibly at a lower temperature, the carbon burning away and leaving silica behind. For this reason, carbide bricks cannot be used at very high

temperatures though when heated in air at 1600° C. to 1800° C. the residual silica melts, coating the underlying carbide with an almost impervious film and so producing bricks which can remain in use at this temperature for several months at a time.

Chemical Composition.

Carborundum bricks usually contain from 77 to 90 per cent of silicon carbide; 6 to 18 per cent of silica; and 4 to 5 per cent of alumina and iron oxide. In carboxide bricks, silicon oxycarbide replaces the silicon carbide.

Crushing Strength.

One of the most important properties of carborundum bricks is their great strength. When properly made they have a crushing strength, when cold, of about 5,700 lb. per sq. in. and some have been made with a crushing strength as high as 9,650 lb. per sq. in. This is eight or ten times as great as that of fireclay bricks, and they do not soften gradually like fireclay bricks.

At very high temperatures the strength decreases owing to the dissociation of the carbide.

Volume Changes on Reheating.

Carbide bricks have a very low coefficient of expansion so that they may be heated and cooled without any appreciable change in volume.

Sensitiveness to Sudden Changes in Temperature.

On account of their low coefficient of expansion carbide bricks are almost completely insensitive to

changes in temperature and do not, therefore, crack and spall in situations where many other refractory bricks could not be used.

Other Properties

Carborundum bricks have a very high thermal conductivity, a fairly high electrical conductivity, together with a high resistance to abrasion on account of their hardness.

Summary.

Carborundum bricks are highly refractory and have a low coefficient of expansion, so that they are very useful in furnaces where the temperature changes rapidly. These bricks have not, as yet, been used to any very great extent on account of their high cost.

ZIRCONIA BRICKS

During the past few years, bricks made of zirconia have been placed on the market. They are made by mixing crude zirconium oxide with a bond such as alumina, clay, thoria, colloidal zirconia, or a temporary bond such as dextrin. The bricks are moulded by hand or pressed in a machine and, after careful drying, are burned at from 1400° to 1500° C.

Colour.

Pure zirconia is quite white, but the bricks are usually a grey or bluish colour; if heated to a very high temperature they turn reddish-brown owing to the formation of zirconium nitro-carbide.

Texture.

The texture of zirconia bricks is not of great importance as the materials are very resistant to sudden changes of temperature, to slags and to abrasion. In general, the texture should be fairly fine so as to secure maximum durability.

Zirconia bricks are particularly resistant to slags, molten metals, fumes, etc., even at the highest temperatures attainable in industrial furnaces, but they are attacked by sodium compounds, pyrites, and substances containing fluorine.

Porosity.

Zirconia bricks are usually fairly porous but this does not detract from their special qualities. The porosity depends largely on the bond used.

Specific Gravity.

Bricks made of fully-shrunk zirconia have a specific gravity of 4.6 to 4.8.

Refractoriness.

No precise figure can be given for the refractoriness of zirconia bricks; it certainly exceeds that of most other refractory materials, for which reason these bricks are particularly suitable for use in electric furnaces where the conditions are especially severe.

Effect of Pressure at High Temperatures.

When heated under a load of 50 lb. per sq in., zirconia bricks fail at from 1450° to 1600° C., according to the bond used in their manufacture.

Volume Changes on Reheating.

Zirconia is almost insensitive to sudden changes of temperature, and zirconia bricks may be heated until white hot and then plunged into cold water without risk of fracture.

Other Properties.

Zirconia bricks are characterized by a very low thermal conductivity which renders them very useful for high temperatures. The specific heat is also very low and does not appreciably increase at high temperatures. Unfortunately, zirconia has a tendency to form nitrides and carbides, at high temperatures, and these substances reduce its durability.

Summary.

On account of their great refractoriness, resistance to corrosion, low thermal conductivity and low coefficient of expansion, zirconia bricks are valuable. They have not yet been used to a great extent, largely as a result of bricks made of very impure zirconia being placed on the market. When purer zirconia is used, the value of bricks made therefrom will be increasingly realized, especially for extremely high temperatures in the presence of corrosive substances. The cost of such bricks is prohibitive for ordinary work.

BLOCKS AND "SHAPES"

Blocks of all kinds, including the "shapes" used for arches and other portions of furnaces, where

specialty-shaped pieces are advantageous, are made of the same materials as firebricks. Fireclay, grog, silica, and magnesia are, however, used far more extensively for these purposes than any other materials.

Except for the differences in their shape and size, these blocks do not differ greatly from firebricks made of the same materials, but the larger blocks are far more difficult to produce because they are much more "tender" and very liable to crack or "twist" during drying and burning.

On account of their size and low thermal conductivity, larger blocks are sometimes burned unevenly and, when broken, show discoloured cores. This is particularly serious in the *tank blocks* used for glass-melting furnaces, and in the blocks used in the hearths of reverberatory furnaces. This defect can only be prevented by slow and skilful burning.

Large blocks are more sensitive than smaller ones to sudden changes in temperature, and consequently special attention should be paid to their porosity in order to keep this sensitiveness at a minimum. When the blocks are also required to resist abrasion or corrosion (for which purposes a dense exterior is necessary), there is often considerable difficulty in producing durable blocks. A dense surface often tends to induce spalling and flaking—which must be avoided—whilst a more open texture is less resistant to corrosion and abrasion. The skill of the block manufacturer lies in combining these opposing qualities to the best advantage.

Stoppers

The outlets of furnaces through which slags, etc., are discharged, are controlled by plugs or stoppers which are usually made of fireclay. They are moulded by hand in the same manner as bricks and, apart from their shape, present no special features. They are quite cheap, are easily broken in the ordinary course of usage, and need not be made of exceptionally refractory material as they are so readily renewed.

CHAPTER II

REFRACTORY HOLLOW-WARE

THE term "hollow ware" includes all vessels and articles with a hollow interior, but in the case of refractory articles it has special reference to crucibles, cupels, glasshouse pots, retorts, muffles, ladles, nozzles, pipes, channels, and a large variety of appliances, used in chemical and other industries, in which acids are heated. Many of these appliances are made of stoneware, which can scarcely be regarded as refractory (*see* p. 1) but the use of fused quartz—particularly that form of it known as "Vitreosil"—has increased rapidly during recent years. Most of these articles are made of fireclay—with or without the addition of grog (p. 80)—but for special purposes, some of the other refractory materials are preferable.

CRUCIBLES

Crucibles are vessels in which materials are heated to a high temperature either for the purpose of fusing them, or in order to calcine them or to permit certain chemical reactions to take place, as in the smelting of some metallurgical ores.

Shape.

Crucibles vary in shape from tall narrow vessels, sometimes wider at the top than the bottom, to short, squat vessels of relatively small capacity.

These differences are largely due to the fact that crucibles are used for many different purposes, and it is important to adapt their shape to the requirements of the user. Typical shapes are illustrated in Fig. 3.

In order to allow the heat to pass into the interior of the crucible as rapidly as possible, the walls should be as thin as is consistent with the minimum permissible strength.

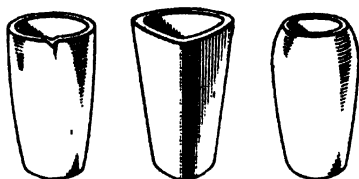


FIG. 3. —CRUCIBLES.

Dimensions.

Crucibles vary in size from that of a large thimble to vessels 30 in. or more in height, and in capacity from about half an ounce of water to 10 gallons or more.

Texture.

Crucibles usually have a fine and somewhat porous texture, except internally where they are often dense, but they vary greatly according to the purposes for which they are used. In all cases the particles should be small, for uniformity in texture is of great importance in all articles required

to be heated and cooled alternately. It is especially important that a laminated structure should be avoided, as this is a source of weakness.

Porosity.

For simple calcination, a porous crucible is wholly satisfactory, but for heating corrosive materials and for melting various substances, great density—at least internally—is essential. Some crucibles are so dense that they can only be used once with safety and, even then, they have to be heated very cautiously until they attain a red heat.

Refractoriness.

The refractoriness of a crucible depends upon the materials of which it is made (*see* Chapter I). For most purposes, fireclay crucibles (with a refractoriness corresponding to Cone 32) are the best, but, for special work, crucibles made of corundum, corundum, zirconia, fused quartz and even magnesia are used.

Chemical Composition.

Fireclay and grog crucibles have a composition similar to the clays of which they are made and to the corresponding firebricks (pp. 14, 78 and pp. 24, 80). *Hessian crucibles* are formed from a mixture of sand and fireclay and are specially used for melting gold, silver, and other precious metals.

Plumbago or graphite crucibles are made of fireclay and plumbago or graphite, and are specially resistant to sudden changes in temperature; they also exercise a slight reducing action on their contents.

Porcelain crucibles are used extensively in chemical laboratories on account of their resistance to most of the substances heated in them, and to sudden changes in temperature.

Crucibles made of *fused quartz* are used for the same purpose and are even less affected by sudden heating and cooling. Crucibles made of pure *zirconia* are exceptionally resistant to sudden changes in temperature, but are very difficult to produce. Small crucibles made of dead-burned *magnesia*, *lime*, or *corundum*, are also used occasionally for special purposes on account of their high refractoriness and insensitiveness to temperature changes.

Cupels.

These are very shallow crucibles with a very thick base. They are made of compressed bone-ash, and are chiefly used on account of their great power of absorbing certain fusible oxides. Thus, if a mixture of gold, silver, and base metal is surrounded by lead foil and heated on a cupel, the lead and base metal will be oxidized and the lead oxide will readily fuse and dissolve the other oxides. The fused material "wets" the particles of bone ash and so is able to penetrate between them and to be absorbed by the cupel, whilst the pure gold and silver (which do not "wet" the bone ash) will remain behind on the surface of the cupel.

Strength.

Large crucibles are required to possess great mechanical strength in order that they may safely

be lifted with their contents. Thus, some crucibles, each containing more than 1 cwt. of molten steel, have to be lifted from the furnace and their contents poured gently into moulds. No standard specifications have yet been prepared for crucibles, but it is obvious that where the risk of serious accidents due to the collapse of a crucible is so great, there is little desire to vary the composition or mode of manufacture when the present ones are reasonably satisfactory.

Effect of Contents at High Temperature.

The contents of a crucible—more especially in the larger ones—have two important influences: (1) they may impose a great stress on account of their weight or, if molten, by their pressure; and (2) they may seriously corrode the crucible. The former is counteracted by the use of crucibles with moderately thick walls, made of sufficiently plastic fireclay to produce a material of ample strength even at the highest temperatures attained in use (it seldom exceeds 1550°C.); whilst corrosion is resisted by carefully selecting the materials of which the crucibles are made, and by giving the interior a dense skin or compact surface which will offer great resistance to corrosion. In some industries, the corrosion is so great that crucibles can only be used once or twice; in others, they are in constant use for several weeks at a time. When very corrosive substances—rich in metallic oxides or sulphides—are to be heated, it is desirable to make extensive trials with crucibles made of different

materials. The trials should be framed on the general principle that basic materials should be heated in crucibles made from basic materials, and acid-reacting materials in clay crucibles. Plumbago crucibles are often useful because of the great inertness of this material to both acid and basic substances.

All crucibles tend to soften at the highest temperatures attained in use, but many workers claim that this is a slight advantage, as it ensures a better and surer grip with the tongs when the crucibles are lifted out of the furnace.

Sensitiveness to Temperature Changes.

Most crucibles must be heated or cooled cautiously as they are sensitive to sudden changes in temperature. Hessian crucibles, and others containing a large proportion of free silica, require special care in this respect. The least sensitive crucibles are those made of graphite, grog, fused quartz, and fused zirconia.

GLASSHOUSE POTS

Glasshouse pots (Fig. 4) are best regarded as very large crucibles used for melting various materials in order to form glass. Owing to their great size (some of them are 5 ft. in diameter) and the pressure of the molten glass in them, they offer a serious problem both to manufacturers and users. They are almost invariably made of fireclay and grog, several clays of different properties being mixed in

suitable proportions in order to secure the necessary rigidity and resistance to corrosion.

Some glasses have a highly corrosive action on burned clay, but with most of the glasses in regular use the action is largely confined to the surface of the pot and does not penetrate to any serious depth, so that some pots are in constant use for a year or more. The durability of the pots depends almost as much on the manner in which they are treated when in use as on the care and skill exercised in their manufacture.

Thus pots which have been thoroughly well-fired prior to use, so as to ensure a maximum development of sillimanite (p. 19), are much more durable than those which have been less fully heated. Much may also be done by treating the interior surface of the pots with molten glass (cullet) prior to the first filling.

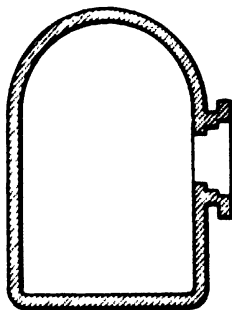


FIG. 4.
GLASS-MELTING POT.
(Cross Section.)

SAGGERS

Saggers are refractory cases in which pottery and other articles are heated in kilns so as to support and protect the articles placed in the saggers from the direct action of the kiln-flames. They are highly important to manufacturers who use them


and are employed in such large quantities that they are largely made on the works in which they are used or in an adjacent works. For further particulars regarding them, the reader should see the author's *Refractory Materials ; their Manufacture and Uses*.

RETORTS

Retorts are vessels in which various materials are heated, in order to produce from them a gas or vapour which it is desired to collect, either in the gaseous or condensed form. They are made of glass, iron, copper and other non-refractory materials as well as of fireclay, fused quartz, etc.

Refractory retorts are chiefly used for two purposes : (1) the carbonization of coal, oil-shale, etc. ; and (2) for the separation of zinc from its ores.

Retorts for Carbonization.

For the manufacture of illuminating gas, the retorts are of several kinds, the best known being  shaped vessels,* closed at both ends and fitted with an outlet pipe through which the gases escape. These retorts are filled with coal and heated to redness by external fires. When all the gas has been evolved, the retorts are opened, the residual coke is drawn or pushed out and the hot retorts are refilled with coal.†

In order that they may be sufficiently durable,

* Vertical retorts are built almost wholly of fireclay or silica bricks (Chapter I).

† See *Our Town Gas Manufacture*, by R. Staley ("Pitman's Technical Primer Series," 2s. 6d. net).

such retorts must be refractory, strong, and not unduly sensitive to sudden changes in temperature. With some coals it is also necessary that the retorts should be able to resist the action of corrosive salts present in the coal.

Texture.

It is important that the surface of retorts should be free from holes and flaws and that these should not be obscured by "washing" or other treatment. The retorts should be reasonably accurate in shape, a variation of $\frac{1}{2}$ per cent longitudinally being regarded as the maximum. A retort 6 ft. in length should certainly not be bent more than $\frac{3}{4}$ in. out of truth.

The texture of retorts used for the manufacture of coal-gas should be relatively coarse so as to withstand the sudden changes in temperature. As a fine deposit of graphite rapidly forms in the interior, there is seldom need to make the retorts specially resistant to corrosion: indeed that would involve an undesirable reduction in their resistance to sudden changes in temperature.

According to the Standard Specification of the Institution of Gas Engineers, fireclay gas-retorts should be made of "sufficiently seasoned raw clay and clean burnt grog. No grog shall be used which will pass through a test-sieve having 16 meshes to the linear inch." In other words, no particles of grog used for this purpose are to be less than $\frac{1}{16}$ in. in diameter.

It is sometimes considered that this specification

permits the use of material which is too coarse, and that the desired insensitiveness to sudden changes in temperature would be better secured by the use of a smaller proportion of coarse material.

Porosity.

Gas retorts should be made of porous materials so as to resist sudden changes in temperature as much as possible. The Institution of Gas Engineers has specified that the "apparent porosity shall not be less than 18 per cent by volume," which is equivalent to about $8\frac{1}{2}$ per cent by weight. Highly porous retorts are leaky when first used, but the graphite lining, which rapidly forms, chokes many of the pores and makes the retorts gas-tight.

Refractoriness.

The refractoriness of fireclay retort material, like that of fireclay bricks, depends on the refractoriness of the raw materials used. There is no difficulty in making retorts, pieces of which, when cut off for testing, will show a refractoriness equal to that of Cone 30 or 32, but the Standard Specification of the Institution of Gas Engineers only requires a refractoriness equal to Cone 28.

Chemical Composition.

Gas retorts are chiefly made of fireclay and grog but for some years there has been an increasing use of silica bricks (p. 27) for this purpose, on account of their higher thermal conductivity. The chemical and mineralogical composition of fireclay retorts is

similar to that of grog bricks (p. 24). Retorts made of bauxite or graphite and fireclay, carborundum, corundum, chromite, and fused quartz are used to a much more limited extent, and these materials are too costly for large retorts.

Crushing Strength.

There is seldom any difficulty with regard to the crushing strength of gas retorts unless they are made of material deficient in fine clay, or unless the retorts are seriously under-burned in course of manufacture.

Effect of High Temperatures in Use.

Gas retorts deteriorate chiefly as a result of the sudden changes in temperature to which they are subjected, and of the corrosion of the retorts by flue dust. The latter has a gradually increasing corrosive effect which cannot be wholly avoided. A minor amount of destruction is also effected by the salts present in the coal in the retorts, and by the retort material acting as a catalyst and decomposing some of the gaseous hydrocarbons evolved from the coal, and depositing free carbon in the pores of the retort. The effect of any basic oxides occurring as impurities in the clay also continues as the retorts are used, but their total effect is seldom serious.

Resistance to Abrasion.

As the materials to be heated are usually charged into the retort whilst it is still hot, it is important that the interior surface of the retort should be

hard enough to resist any abrasion by the charge. This resistance is sometimes increased by glazing the interior of the retort.

Shrinkage on Reheating.

There is some risk of collapse if gas retorts shrink unduly in use and it is therefore desirable, when ordering, to specify a maximum permissible shrinkage. The specification of the Institution of Gas Engineers requires a linear shrinkage or expansion not exceeding $1\frac{1}{4}$ per cent when the test piece ($4\frac{1}{2}$ in. square) is reheated to Cone 14 for two hours and then allowed to cool.

Conductivity.

It is very important that retorts should have a high capacity for transmitting heat to their contents, or an unnecessarily large amount of fuel will be used. Silica retorts appear to have a slightly higher thermal conductivity than fireclay retorts; those of carborundum are much more highly conductive, but their cost is usually prohibitive.

For further information, see *Muffles* (p. 73); also the author's *Refractory Materials; their Manufacture and Uses*.

Retorts for Shale.

In many cases, iron retorts are sufficiently heat-resisting to be used for the production of oil from shale. Where more refractory retorts are required, they are very similar to those used for the carbonization of coal.

Retorts for Zinc.

The retorts used for the distillation of zinc are made of fireclay to which a small proportion of grog is sometimes added. As zinc oxide has a highly corrosive action on fireclay (forming a spinel composed of zinc aluminate), it is necessary for the retorts to have a compact interior surface to reduce this corrosion to a minimum. On the other hand, the retorts as a whole must be sufficiently open in texture to enable them to withstand the sudden changes in temperature to which they are subjected when in use.

The general properties of the retorts used for zinc should be the same as those of gas retorts (pp. 68 to 72), except that they should, as far as permissible, have a denser interior surface.

MUFFLES

Muffles are chambers in which articles or materials may be heated without being exposed to the direct action of the flame. The interior walls of an ordinary domestic oven really form a muffle, but the term is usually limited to structures made of refractory materials.

Muffles are of all sizes from those 8 in. \times 3 in. \times 3 in. used by amateur enamellers to those 10 ft. \times 8 ft. \times 8 ft. used in the pottery and enamelled ironware industries. The smaller ones are made in one piece (see Fig. 5) of fireclay—with or without grog—carborundum, corundum or fused quartz; the larger ones are built of bricks or slabs made of either fireclay, silica or carborundum.

The essential features of a muffle are: (1) it must exclude all flame and flue dust from the articles or materials to be heated; (2) it must permit sufficient heat to enter the interior of the muffle to raise its contents to the desired temperature; (3) it must be sufficiently insensitive to sudden changes in temperature to be durable under all ordinary conditions of use.

The first and third requirements are best met by

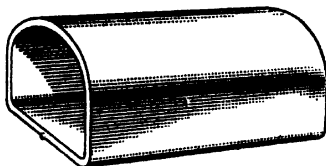


FIG. 5.—MUFFLE.

the use of fireclay and carborundum, but unfortunately, fireclay is inferior in thermal conductivity to silica and carborundum, though much cheaper than the latter. In muffles which are heated and cooled very slowly, silica is excellent, though crushed silica is very difficult to use in the case of one-piece muffles and, if mixed with sufficient clay to render it plastic, it is inferior to muffles made of fireclay alone, particularly if part of the fireclay has been previously heated and so converted into grog.

Muffles and gas retorts are so much alike in the properties they are required to possess, that the reader should refer to pp. 68-72, and in ordering or designing muffles should require characteristics

and limitations similar to those mentioned in the section on retorts. The chief difference is that most muffles are not subject to such violent changes in temperature as are many retorts, and may, therefore, be made of a material which is rather more sensitive to sudden heating and cooling.

LADLES

In some of the metal-working industries, the molten metal is received from the furnace in a ladle, which is carried to the ingots into which its contents are slowly poured. Where the temperatures attained by the metal are not very high, almost any fireclay bricks can be used for the ladle, but when the latter is to receive molten steel or other high-temperature alloys greater skill is necessary in selecting the refractory material. Such material must be highly resistant to corrosion by any slag floating on the metal, and it must be equally insensitive to the sudden changes in temperature which occur when the ladle is filled and emptied. As these two properties are incompatible, a perfect lining for ladles is impossible when fireclay, magnesia or silica bricks are used. Fused quartz would be excellent (except in the case of metals containing basic slags) were it not so costly, and corundum and zirconia would offer possibilities if they were less expensive.

Under present conditions, the best material for lining ladles is fireclay bricks, except for metal containing basic slag, when magnesia bricks should be used. In both cases, the refractory material

should be thoroughly well burned and the joints should be as thin as possible.

PIPES, NOZZLES AND CHANNELS

The nozzles, pipes, channels or outlets for furnaces containing molten metal, slag, frit, glass, enamel, etc., should be made of a refractory material which is as resistant as possible to that with which it comes in contact. It should also be reasonably insensitive to sudden changes in temperature. Unless the molten material is highly basic, the nozzles, pipes, etc., are best made of fireclay of a moderate degree of fineness, such as that which passes completely a 24-mesh sieve. Smoothness of finish and fineness of texture are of great importance in such nozzles, etc.; hard burning is not essential, and in some cases under-burned articles have proved more durable than those which are more thoroughly fired. Great durability is seldom necessary as these articles are inevitably damaged by rough usage in cleaning, etc.

SUNDRY REFRACTORY ARTICLES

Some articles require to have parts of a highly refractory nature though they may not be so as a whole. Thus the "tips" of acetylene gas-burners, the nozzles of "inverted" gas-burners, the so-called "asbestos fuel" or "radiators" used in gas-stoves, the rings or supports of the mantles used in incandescent gas lighting, and the parts of electric radiators or furnaces which come in contact with the hot wire must all be refractory, though the

remainder of the articles of which they form a part may be of metal or other non-refractory material. Such articles are usually made of finely ground fireclay with or without asbestos or crushed silica rock. Mantle-supports and rings are often stated to be made of magnesia, but most of those examined by the author have been made of a finely ground mixture of clay and silica rock.

CHAPTER IV

RAW REFRACTORY MATERIALS

REFRACTORY materials, as distinct from the articles made from them, are used for a variety of purposes, including rammed linings of furnaces (for which the material is moistened, laid in the furnace, and consolidated by ramming or tamping). Sometimes the bottom or hearth of the furnace is merely covered with a layer of sand, ground ganister, dolomite, or other refractory material, and in other cases the interior is plastered or "pointed" with a paste which may be made of a mixture of raw and burned fireclay, silica and fireclay, or a more complex mixture containing water-glass Portland cement, or other special binding agent.

The more important of the raw refractory materials are described in this chapter. Very much fuller details will be found in the author's *Refractory Materials; their Manufacture and Uses* (Griffin).

FIRECLAYS

The term "fireclay" has long been seriously misunderstood and—particularly in mining records and survey reports—it has been applied to the under-clays or seat-earths lying immediately below coal seams, quite regardless of whether such materials were clay or not, and without paying any attention to their true nature. The origin of

this error probably lies in an over-hasty conclusion of a very eminent geologist, long since deceased, who seems to have imagined that because fireclays occurred immediately beneath many coal-seams, they occurred under all! This is by no means correct, as a little careful investigation will show.

Fireclays are distinguished from most other clays by their greater refractoriness (p. 1) though, curiously enough, the term "fireclay" is seldom applied in this country to china clay, or to any deposits except those associated with the Coal Measures, though not necessarily in direct contact with coal.

Fireclays are found in seams or beds which vary from a few inches to about 5 ft. in thickness. Much thicker seams are sometimes reported but, on examination, will usually be found to include a rock of a different character and largely devoid of plasticity.

Fireclays occur to a variable extent in all the coal-bearing areas in this country, some of the most notable being those found in Central and South Yorkshire, Northumberland, Durham, Lancashire, Staffordshire, Warwickshire, Leicestershire, Derbyshire, Shropshire, Gloucestershire, Somerset, Kent, Devonshire, and North and South Wales, and at Glenboig, and Bonnybridge in the south of Scotland.

Pocket Clays.

Among the materials used for the manufacture of firebricks are the so-called "pocket clays" of Derbyshire and Staffordshire. These occur in large pits or pockets and appear to be the residue left

when limestone rocks have been eroded and dissolved by the action of water rich in carbon dioxide.

These pocket clays are highly siliceous and their chief value consists in the fact that the proportion of silica and clay in them is such that the bricks neither expand nor contract when heated. This is due to the expansion of the silica neutralizing the effect of the shrinkage of the clay, thereby giving a product of constant volume.

These clays are not so refractory as the purest fireclays but they are in great demand for coke-ovens and for retorts and settings used in gas manufacture.

Artificial mixtures of clay and silica which possess the same properties as the pocket clays, are used in the manufacture of semi-silica bricks (p. 39).

Texture.

Fireclays, when mined and brought to the surface are in the form of irregularly-shaped lumps of various sizes. On exposure to weather, some of these fall to powder whilst others are only slightly affected. When cut, most fireclays show a fine, uniform texture, and on being rubbed they develop a slight polish. Under prolonged treatment with water they are reduced to a fine powder which, on being stirred, forms a greyish cream or slurry. If the latter be placed on a 100-mesh sieve and shaken the greater part of it will pass through, leaving a residue which—apart from the larger size of the particles—is indistinguishable from that which passes readily through the sieve. A few harder and more stony particles are often present.

Refractoriness.

No British fireclays have a refractoriness greater than that of Cone 35 and most of them correspond to Cones 30 to 32, whilst some "bastard fireclays" are only equivalent to Cone 26 or are even less resistant to heat.

Melting Point.

Fireclays have no definite melting point but fuse gradually over a long range of temperature commencing at about 1700° C. in the better materials, and at about 1550° C. in the inferior ones. This great range of fusion is partly due to their low thermal conductivity and partly to the number of impurities they contain.

Chemical Composition.

Fireclays, like other clays, are complex compounds of alumina, silica, and the elements of water, but they also contain variable proportions of free silica, carbonaceous matter—probably of remote vegetable origin—and small proportions of various silicates, carbonates, and other compounds of iron, lime, magnesia, sodium, potassium, titanium, vanadium, manganese, phosphorous, sulphur, chlorine, etc. A chemical analysis shows that the composition of fireclays in different districts varies considerably; even in different parts of the same seam the variations in composition are sometimes very striking. The figures shown in Table IV on page 82 are typical.

TABLE IV.—ANALYSES OF FIRECLAYS.

	Leeds, Central Yorks.	Stanning- ton, S. Yorks.	Stour- bridge, Staffs.	Durham.	Dowlais, S. Wales.	Glenboig, Scotland.
	%	%	%	%	%	%
Silica	71	48	64.0	62	67	46
Alumina	20	35	23.0	25	21	36
Ferric Oxide	1.5	3	2.0	1	1.5	2
Lime	0.5	1	0.7	0.1	0.5	—
Magnesia	—	1	—	0.5	0.8	—
Soda	1	1.5	—	1	2	0.5
Potash	—	—	—	—	—	—
Loss on Ignition	6	10	10.3	10	7	14.5

The chief impurities are the same as those mentioned on pp. 14 to 21. The carbonaceous (vegetable) matter burns away when the clays are heated to a sufficiently high temperature in a current of air. If the conditions of heating are unfavourable to the complete combustion of this material, dark cores are formed in the heated fireclay.

Mineralogical Composition.

Fireclays are extraordinarily difficult to examine petrographically, as most of the particles present do not show definitely recognizable characteristics. So far as can be ascertained, they are highly complex aluminosilicic acids with very variable proportions of other minerals as impurities. On treating a ground fireclay with a dilute solution of sodium carbonate or other suitable alkali, the "true clay" present may be brought into suspension whilst the greater part of the "impurities" settle and may be removed by decantation. The extremely fine particles so separated do not admit of definite

mineralogical identification. Like other colloidal materials they possess properties which belong to their physical state rather than to their chemical or mineralogical composition.

So far as has been ascertained, the essential constituent of fireclays is in the form of extremely minute particles, of no definite size or shape, each particle consisting of an invisibly small core which is surrounded by a relatively thick covering of a soft jelly-like material. When it is remembered that even the largest particles of true clay are not more than 0.004 in. in diameter, it is easy to see that any precise mineralogical identification of the smaller particles is almost impossible.

Many of the coarser particles present in fireclay are equally difficult to identify; most of them appear to be indurated agglomerations of the smaller particles together with a small proportion of quartz and other minerals of little importance.

Acidic Character.

The essential constituent of fireclay (i.e. "true clay") is wholly insoluble in water, and all acids except hydrofluoric acid, so that its true chemical character is difficult to ascertain. When heated with alkalis or with lime or other solid bases, and even with some stable salts, as sodium chloride, (common salt) clays act as true acids and form definite compounds. Unfortunately, the temperature at which these reactions occur is usually so high as to involve the decomposition of the clay with the result that silicates and aluminates are

formed, though the clay itself appears to be of the nature of a complex acid, and is termed an aluminosilicic acid. There is evidence that there is no single substance to which the term "true clay" can be exclusively applied, but that, on the contrary, there are many aluminosilicic acids, differing considerably in the proportions of silica and alumina they contain, but all composed essentially of these two oxides together with the elements of water, all united so as to form a series of insoluble aluminosilicic acids, having the general formula $x\text{Al}_2\text{O}_3 \cdot y\text{SiO}_2 \cdot z\text{H}_2\text{O}$. In the case of china clay the formula becomes $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, whilst several of the more widely used fireclays, when carefully separated from free silica and other readily removable impurities, would be more nearly represented by $\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. The great variations in the composition of different fireclays suggests, however, that they are mixtures of silica with some substance corresponding in composition to china clay, though not necessarily identical with it.

The subject is complicated by the colloidal properties of clays, because colloidal alumina and colloidal silica can, under certain conditions, mutually precipitate each other, forming substances of very variable composition and closely resembling clays, though not identical with them. The difference between such artificial colloidal precipitates and natural clay lies chiefly in the fact that, hitherto, it has not been possible to precipitate colloidal silica and alumina around a sufficiently minute core of inert material, so as to represent accurately what is

now regarded as the most probable constituent of plastic clays.

Behaviour with Water.

Fireclay, like other clays and most colloidal hydrogels, behaves in a very peculiar manner with respect to water. A lump of clay will gradually fall to pieces in still water and the product will have increased in volume, owing to the absorption of water by the particles. If the proportion of water is sufficiently large, the mixture forms a slip or slurry which does not readily become clear on standing, and has some remarkable powers of withdrawing certain dyes and salts from their solutions. With a smaller proportion of water (usually about 20 per cent) a paste is produced which can be moulded or pressed into almost any desired shape. Moreover, if a portion of this paste is torn from the mass and pressed on to any other part of it with a slight rubbing motion, the two pieces of clay will adhere and if the operation has been skilfully performed, no joint will be visible on making a section perpendicular to the plane where the joint is expected. This power of cohesion enables many articles to be modelled in clay which would otherwise have to be carved; it also enables handles to be placed on jugs, etc., without the use of any adhesive.

Elasticity.

One of the most valuable properties of fireclays is their plasticity or ability, when mixed with a

suitable proportion of water, to retain any desired shape which may be given to them by the application of a slight pressure. It is this property which enables clay pastes to be used so successfully in the manufacture of bricks, tiles, terra-cotta, hollow-ware, and all the shapes desired in the various clay-working industries.

The causes of plasticity are too complex to be explained fully in these pages ; it must here suffice to state that plasticity appears to be due to the power of the extremely small particles of clay to retain a relatively large film of soft, gelatinous material around each particle, this film having sufficient adhesiveness to prevent the particles from separating, even when subjected to severe stresses, and also sufficient mobility to enable the particles to move over each other so that the plastic mass readily assumes any desired shape. In this respect, plasticity appears to depend largely on the existence of particles each consisting of a minute core surrounded by material in the state of a colloidal gel.*

* When a plastic clay is dried at a low temperature it loses its plasticity and becomes hard and rocky. The plasticity may be restored by grinding the material to powder and mixing it with a suitable proportion of water. If the material has been dried at a temperature sufficient to destroy the colloidal

* For further information on the nature of this gel the reader should study the subject of "colloids" and also the "Report on the Colloidal Nature of Clay" in the *British Association Report VI on Colloids and their Industrial Application*, published by H.M. Stationery Office.

matter in the clay (almost any temperature above 100° C. will do this), the plasticity cannot be completely restored as the constitution of the clay is altered by the heating.

Binding Power.

Closely allied to plasticity is the binding power of clays, whereby they are able to impart plasticity to finely-ground materials with which they are mixed; that is to say, the mixture is plastic enough though to a less extent than the original clay. This property is extremely useful in controlling the shrinkage of clays and in modifying their properties in other ways.

Shrinkage.

Any clay which has been mixed with water and converted into a paste of suitable consistency for moulding or modelling will shrink or contract when dried, and will undergo a further smaller contraction when heated to redness or any higher temperature. This shrinkage is due in the first place to the particles of plastic clay being separated from each by a film of water, so that they move close together when this water is removed by drying the clay. On heating to redness, the clay is decomposed, forming still smaller particles and at a yet higher temperature partial fusion occurs, the result being a still further reduction in the volume of the mass.

Clays which have more than 8½ per cent linear shrinkage (i.e. more than 1 in. per linear foot) must usually be mixed with some non-plastic material,

or they will crack during drying. Either crushed grog (p. 89) or silica rock is usually employed for this purpose.

Effect of Heat.

Briefly, the results of heating a fireclay to any temperature likely to be attained in an industrial furnace are as follows—

(1) The moisture in it is evaporated and the clay is dried. This is accompanied by a moderate amount of shrinkage.

(2) At the lowest visible red heat, the clay begins to decompose, evolving a further quantity of water. This is accompanied by a farther slight shrinkage and by complete loss of plasticity. When the decomposition is complete the clay is converted into a harder material of a stony character.

(3) On being heated to a yet higher temperature, the more fusible constituents of the clay begin to melt. Those of a basic or alkaline character begin to form fusible silicates, which gradually dissolve more of the material, and eventually the pores are filled with a glassy or slag-like substance. When the clay no longer contains any voids it is said to be "vitrified." Complete vitrification is seldom reached with a fireclay. When the amount of molten material is sufficient, the mass loses its shape, the temperature at which this occurs depending largely on the shape of the mass. Thus, a thin rod supported at each end will show a change of shape (by sagging) at a much lower temperature than a cube of the same material.

- (4) Simultaneously with the decomposition of the clay, any vegetable matter present burns away. Under conditions of rapid heating, this may form a black core with more or less swelling of the material owing to the production of gas in the pores of the clay.

Other Properties.

Many of the useful properties of fireclay can be deduced from those of fireclay bricks. Thus, the true specific gravity is about 2.6; and the thermal and electrical conductivities are about the same as those of firebricks. Use is sometimes made of the magnetic properties of some of the impurities in clays in order to purify the latter.

GROG

Grog or *chamotte* is made by burning fireclay at a temperature sufficiently high to destroy its plasticity. It is usually desirable, however, to heat the clay to a temperature similar to that at which the refractory articles will be used. By this means, the shrinkage of the grog when in use, with all the disadvantages of such shrinkage will be avoided. For this reason, the fireclay intended for grog should be burned at a temperature not lower than 1300°C. and preferably at 1400 to 1500°C.

The best method of making grog is to grind the fireclay to a coarse powder, mix it with water in a pugmill so as to convert it into a paste, shape this into rough bricks by the wire-cut process (p. 120) and burn the bricks in the customary manner. The

bricks are examined after they have been taken out of the kiln and any obvious impurities are rejected. The remaining material is then crushed to a coarse powder and passed over two sets of screens; the first screen separates the material which has not been ground sufficiently, and the second screen separates the dust.

For most purposes, grog should not contain any particles larger than $\frac{1}{8}$ in. diameter or smaller than $\frac{1}{16}$ in.

Grog has the same general properties as firebricks made from the same clay, but bricks made of grog and fireclay have several advantages over those made solely of unfired clay. The preliminary burning during the manufacture of the grog enables impurities to be seen and the pieces of grog containing them to be removed instead of allowing them to enter the bricks. There is also a slight reduction in the proportion of alkalies as a result of the double burning—first as grog and then as bricks. The sizes of the various particles of grog can be regulated and the resultant bricks can, by that means, be made more resistant to sudden changes in temperature, corrosion, abrasion, etc. Broken firebricks are sometimes used as grog, but unless they are carefully selected and all slag and obvious impurities removed they may do more harm than good.

SILICA

Silica is an oxide of the non-metal silicon and is usually represented by the well-known formula

SiO_2 . By analogy with carbon, the substance represented by this formula should be a gas, whereas silica is a solid which can only be fused with difficulty,* so that its true formula almost certainly is Si_xO_{2x} where x is at least six and may be much greater. Pure silica is obtained as a result of several chemical reactions, one of the best known being that in which a silicate is fused with sodium carbonate, dissolved in water and filtered, the solution then being acidified with hydrochloric or sulphuric acid and evaporated almost to dryness. The silica is then precipitated in a gelatinous (colloidal hydrogel) state and it may be separated by filtration. It may also be obtained from various other silicon compounds, such as the fluoride. When prepared artificially the calcined silica is a very light, white powder which, when intensely heated in an electric arc, fuses to a clear glass and remains glassy on cooling.

Occurrence.

The form in which silica occurs most abundantly in nature is that of the crystalline mineral quartz,* which is the chief constituent of sandstone rocks and sand, and is an important ingredient of granite and many other rocks. The quartz may be in a primary state, having been directly crystallized from a molten magma, or it may be of a secondary character, as in quartzite rocks. Some silica rocks

* Two other crystalline forms of silica, which have not been found in sufficiently large quantities to enable them to be used commercially, are *cristobalite* and *tridymite*, both of which are formed when silica is strongly heated (p. 30).

are composed of particles of quartz cemented together by a film of gelatinous silica; these are among the most useful for the manufacture of silica bricks, etc.

The silica rocks of most importance as refractory materials are—

Dinas rock and similar quartzites which form part of the Basal beds of the Millstone Grit. These are worked chiefly in Carmarthenshire and Glamorganshire, South Wales.

Quartz-schists and conglomerates which are used to a limited extent.

Ganister which occurs principally in the Coal Measures around Sheffield and in the Millstone Grit in the South of Scotland, though fine-grained silica rocks in other localities are frequently termed "ganister." Ganister is particularly useful on account of its self-binding or feebly plastic property. This is due to the clay present in it. The same property may be conferred on other silica rocks by grinding them with clay and water under conditions which will not destroy the angularity of the particles of silica.

Other *silica rocks*, which are similar in chemical composition but somewhat different in texture from true ganister, are found in many parts of the country, including Durham and West Yorkshire, North Wales, Scotland, etc.

Silica sand, which is used to some extent in America.

Flints which are sufficiently free from a calcareous coating are used for silica bricks. They occur on

the sea-shore, in the South of England and near Dieppe in France. Other useful flints occur in small quantities in other isolated areas. Flints are valuable on account of the speed of conversion of the silica into cristobalite and tridymite.

Erratic blocks of Tertiary origin, when composed of almost pure quartzite, are preferred to all other forms of silica by the German manufacturers of silica bricks on account of the comparative ease with which the quartz is converted into tridymite and cristobalite.

Colour.

Silica rocks are usually grey or reddish-brown when viewed in mass, but very small fragments are often as clear and colourless as glass, and all the silica rocks suitable for use as refractory materials are seen, when highly magnified, to consist of clear and colourless particles of various sizes, together with a much smaller number of opaque or coloured particles. White silica rocks are occasionally seen.

Texture.

If a fragment of silica rock is examined closely it will be found to consist chiefly of small particles of glassy quartz, but under a microscope these particles may be seen to be either: (i) interlocked without any visible bond; (ii) united by a glassy magma of almost pure silica; or (iii) united by a very small proportion of clay. The existence and nature of the bond which unites the particles is of great importance to the manufacturer and user of refractory materials. If a piece of silica rock about 2 in.

or more in diameter is placed in a furnace and heated to bright redness, and then cooled rather rapidly—as by withdrawing it quickly—the rock will crack or fall to pieces, if the particles of quartz are unduly large or if the bond is of an unsuitable character. A minute inspection of such a rock under a microscope will usually show that the particles of quartz have actually split or have parted from each other. Such a material is obviously unsuitable for furnace construction. A suitable silica rock, on the contrary, will have the same crushing strength before and after calcination; it will usually, though not invariably, be composed of grains of secondary quartz united by a glassy siliceous matrix.

Refractoriness and Melting Point.

As pure silica is a definite chemical compound it possesses a definite melting point, namely, 1470°C. , but this is only true of very small particles. The thermal conductivity is so low that larger pieces of silica do not show any signs of fusion below 1790°C. (Cone 36) and even the crude silica rocks used for brick manufacture have a refractoriness of Cone 34 to 35. Some of the published figures for the refractoriness of silica rocks and of the bricks made from them are greatly exaggerated.

Chemical Composition.

The smaller the amount of impurities in a silica rock, the better will the latter be for brick manufacture, provided that the physical properties of

the material, are suitable.) Typical analyses are shown in Table V—

TABLE V.—ANALYSES OF SILICA ROCKS.

	Yorkshire.	Durham.	N. Wales.	S. Wales.
	%	%	%	%
Silica	97.0	97.6	97.4	98.7
Alumina	0.7	0.5	1.1	0.3
Ferric oxide	0.9	0.9	0.5	0.3
Calcium oxide	0.1	0.3	0.1	0.1
Magnesium oxide	0.1	0.1	0.1	0.1
Soda	0.1	0.1	0.2	0.1
Potash	0.2	0.1	0.1	0.1
Water	0.9	0.4	0.5	0.3

It is undesirable for the rock to contain more than 5 per cent of alumina and metallic oxides, as these increase its fusibility. The chief "impurity" in ganister is clay which, in moderate proportions, forms a useful bond and does good rather than harm.

Mineralogical Composition.

This has been described on p. 34.

Acidic Character.

Silica behaves precisely like an insoluble acid; it combines, at a sufficiently high temperature, with bases and alkalies forming silicates of varying complexity and fusibility. Thus, with lime, silica forms two silicates— $\text{CaO} \cdot \text{SiO}_2$ (metasilicate) and $2\text{CaO} \cdot \text{SiO}_2$ (orthosilicate), containing respectively 51.7 per cent and 34.9 per cent of silica. When fused, both these silicates form glassy materials which cool to either a glassy or crystalline mass, according to the conditions. Crude calcium metasilicate is

the predominant fused silicate in silica bricks; it is usually contaminated with sodium, potassium and magnesium silicates.

Plasticity.

Silica rocks, even when crushed, are devoid of plasticity, but they develop sufficient cohesion when mixed with milk of lime to enable them to be moulded into bricks and other simple shapes. Crystalline silica, which has been ground in water to an impalpable fineness, and gelatinous silica are both feebly plastic.

Expansion.

When silica rock, or an unfired brick made from it, is heated it expands, the total increase in volume being about 20 per cent; this corresponds to a linear expansion of about $\frac{1}{8}$ in. per brick. Much of the expansion occurs during the burning of the bricks in course of manufacture, but if the burning has not been sufficient the bricks will continue to expand when in use at high temperatures. It is almost impossible to prevent a small amount of expansion in use, as the burning is never fully completed but such expansion is not objectionable if it is less than 0.75 per cent linear.

The expansion is due to the conversion of the quartz in the raw materials to tridymite and cristobalite, which are more bulky forms of silica.

The extent to which a further expansion is likely to occur may be judged from the true specific gravity of the powdered bricks (see p. 31).

Effect of Heat.

The effect of heat on silica is chiefly to convert it into tridymite or cristobalite—the only two forms which are stable at high temperatures. This conversion has been described on p. 30. Silica does not decompose on heating, like clay, but its atoms are rearranged in some way at present not understood, so that the effect of heat is almost the same as if two new compounds had been produced. The change is by no means simple and, on cooling, the silica very slowly reverts to quartz. As the silica is never quite pure, there is always some silicate formed if the material is heated to a high temperature (see p. 95). These silicates fuse and fill up the interstices in the material, thus binding the particles of silica into a hard mass which is very resistant to crushing.

Effect of Water.

The effect of water on silica is ordinarily quite inappreciable, though actually there is a very slight solvent action. In this respect silica rocks differ greatly from clays (p. 85).

Specific Gravity.

The specific gravities of the various forms of silica are shown on p. 31.

Other Properties.

Among the less important properties of silica are its hardness (greater than orthoclase and softer than topaz); its very low thermal conductivity which

makes it excellent for the construction of furnaces, etc., and its resistance to acids, with the exception of hydrofluoric acid, in which it is soluble with decomposition and formation of gaseous silicon tetrafluoride.*

FUSED SILICA

Silica which has been fused in an electric furnace is extensively used for the manufacture of pyrometer tubes, crucibles and other articles of a refractory nature. It resembles glass in many respects, but is much more resistant to heat and is entirely insensitive to sudden changes in temperature. A crucible made of fused silica can be heated to bright redness and then plunged into cold water without any serious effect. This remarkable property is due to the extraordinarily low coefficient of expansion of fused silica.

BAUXITE

Bauxite is a hydrous oxide of alumina of very variable composition and properties. It is chiefly of value as a source of alumina.

Occurrence.

Several deposits of bauxite which are quite useless for refractory purposes occur in different localities, but for furnace linings and the manufacture of firebricks, etc., the relatively pure, white bauxites must be used. The bauxites of the South of France,

* For further information on silica see the author's *Refractory Materials; their Manufacture and Uses* (Griffin).

North America, and India are chiefly used for refractory purposes. The red varieties contain too much iron, but this may be separated if the bauxites are mixed with coke and heated in a blast furnace.

Refractoriness.

The white varieties of bauxite have a refractoriness corresponding to from 1800 to 2000° C. (Cones 36 to 42); some of the red varieties are nearly as refractory when heated in an oxidizing atmosphere, but under reducing conditions the resultant iron melts at about 1550° C.

Chemical Composition.

The bauxites suitable for refractory purposes should consist almost wholly of alumina and water, though the presence of not more than 6 per cent of other impurities is not usually objectionable. The water is removed on heating and thus has the effect of making the proportion of impurities much larger in the calcined bauxite than in the raw material. The chemical composition of bauxite is so variable that no single set of figures can be regarded as typical. Further information thereon will, however, be found in the author's *Refractory Materials; their Manufacture and Uses*.

Mineralogical Composition.

It is highly probable that bauxites originated as colloidal mixtures of ferric and aluminium hydroxides; this would account for their very variable composition and properties. They appear to be wholly amorphous.

Character.

Bauxite, like alumina, sometimes acts as a base and sometimes as an acid. It is attacked by various metallic oxides, forming aluminates in which it plays the part of an acid radicle. It is also attacked by acids; then it acts as a base and forms aluminium salts. When used as a refractory material it is largely neutral, but will act as first described if the circumstances are favourable.

Plasticity.

Bauxite is normally devoid of plasticity, but occasionally portions are found which are slightly plastic.

Shrinkage.

Bauxite shrinks very greatly when heated, and evolves a large, but variable, proportion of water. It is, therefore, necessary to calcine it fully before it can be used in the manufacture of bricks, etc. Fortunately, the greater part of the water is completely removed at temperatures below 1000°C ., so that bauxite does not require so high a firing temperature as some other materials. If raw bauxite is made into bricks, these crack so badly when heated that they are useless.

Effect of Heat.

When raw bauxite is heated it is decomposed, and a variable proportion of water is evolved, leaving a soft, white or creamy amorphous mass

resembling burned fireclay. With the evolution of the water the material shrinks, and on further heating the shrinkage continues though to a much smaller extent. If the heating is prolonged at a temperature of 1700°C . or above, a further shrinkage occurs and the bauxite is converted into a form of corundum. If heated to fusion and then allowed to cool slowly, crystalline corundum is produced. This is the most refractory form of alumina; it has a melting point of about 2000°C .

Specific Gravity.

The specific gravity of raw bauxite is 2.9; on calcination it rises to 3.9 to 3.2; and on fusion and recrystallization it rises to 3.9, the specific gravity of corundum.

As the intermediate amorphous form produced at about 1000°C . is sufficiently stable for most purposes, the denser product is seldom produced on a large scale as a refractory material, though it is extensively used as an abrasive.

Other Properties.

Bauxite is soft and friable, but the corundum produced by heating it to a sufficiently high temperature is one of the hardest substances known. The thermal conductivity of bauxite is similar to that of fireclay but the thermal conductivity of corundum is nearly three times as great.

The chief value of bauxite is as a highly refractory

See *Abrasives*, by A. B. Searle ("Pitman's Technical Primer Series," 2a. 6d. net).

and largely inert material, which can be added to fireclay to increase the refractoriness of the latter. Its use—in the form of corundum—as one of the most infusible materials is growing, but the cost of its production is still regarded as prohibitive to its extended use.*

ZIRCONIA AND ZIRCON

Zirconia—the oxide of the metal zirconium—promises to be one of the most valuable refractory materials yet discovered, on account of its extraordinarily high refractoriness.

It is found chiefly in Brazil, where it occurs in enormous quantities though in a very crude state. Its refractoriness is affected by a very small proportion of impurities, so that the oxide should be carefully purified before use. Attempts to use crude zirconia have led to unsatisfactory results and to some undeserved prejudice against zirconia.

Texture.

The crude zirconia is supplied in the form of a dark grey or brownish sand, but the purified zirconia is in the form of a fine snow-white powder.

Refractoriness.

No reliable figures have been obtained for the refractoriness of pure zirconia; it appears to be extremely high.

* For further particulars see the author's *Refractory Materials; their Manufacture and Uses* (Griffin).

Shrinkage.

The freshly precipitated zirconia shrinks greatly on heating; in this respect it resembles lightly calcined magnesia. When fully heated, however, its shrinkage rapidly ceases.

Other Properties.

Zirconia is so inert that it behaves in a neutral manner to the oxides and bases met with in ordinary furnace conditions but, when in a finely powdered state, it can be fused after mixing with sodium peroxide. It is devoid of plasticity and is quite unaffected by heat, water and acids.

Zircon (zirconium silicate).

This is a highly refractory material which occurs in commercially valuable quantities in Madagascar. It has most of the inertness and high refractoriness of zirconia, but is more difficult to obtain in a pure state. It is slightly inferior to pure zirconia but much cheaper, and is superior to the crude zirconia from Brazil.

MAGNESITE

Magnesite is the material from which magnesite bricks are made. It is not found in commercially valuable quantities in the British Isles, but is imported from Styria, Greece, Australia, Canada, and India.

• Magnesite is a white rock composed of relatively pure magnesium carbonate, though the natural rock

usually has numerous intrusions of other minerals, which must be separated by the quarrymen.

The raw magnesite is quite unsuitable for use as a refractory material on account of its great shrinkage when heated to high temperatures. This shrinkage is partly due to the loss of carbon dioxide which constitutes about 47 per cent of the magnesite, and partly to changes which occur in the resultant magnesia when the latter is intensely heated.

Magnesite is usually calcined in the country in which it occurs and is imported in a calcined state.

Before it is fit for use as a refractory material it should have been heated to such an extent as to render it completely *dead-burned*,* but as this requires prolonged heating at 1700°C ., the imported product will usually be found to shrink considerably on being reheated, even at 1400°C . Properly dead-burned magnesia has a true specific gravity of 3.6 to 3.65, whereas the lightly calcined material may have a specific gravity as low as 3.0.

Colour.

Grecian magnesite is almost white when dead-burned, but the Styrian product is very dark coloured on account of the iron present in it. Iron oxide is sometimes added deliberately to magnesite, in order to reduce the temperature necessary to

* A refractory material is said to be "dead-burned" when it has been heated to such an extent that no further change in volume occurs when the material is reheated at the same or some higher temperature which is not sufficiently high to cause fusion. The reasons for "dead-burning" the magnesite are given on pp. 45 and 46.

"dead-burn" it, though the refractoriness of the magnesite is reduced by this addition.

Refractoriness.

The melting point of pure magnesia is about 2000° C.; the refractoriness (p. 1) of the best commercial dead-burned magnesite is about Cone 38, but when much iron oxide is present the refractoriness is sometimes no greater than that of fireclay or silica.

Chemical Composition.

As previously stated, the dead-burned magnesia should consist of almost pure magnesium oxide, but the presence of about 4 per cent of iron oxide and of about 5 per cent of silica and other impurities, is not usually objectionable.

It should be noted that the most objectionable impurity in magnesia or magnesite is silica; this combines with the magnesia to form fusible silicates which reduce the refractoriness of the material.

Mineralogical Composition.

Magnesite is the crystalline mineral form of magnesium carbonate. When calcined it forms amorphous magnesia, together with a variable proportion of magnesium and other silicates, due to the impurities present. On being heated still further, to a temperature of about 1700° C., the magnesia is converted into a more condensed form which, when crystalline, forms the mineral *periclase*.

consisting of pure magnesia, whilst the impurities in the mass occupy the interstices between the crystals of periclase. Unless the final product (bricks, crucibles, etc.) contains a large proportion of periclase, it will be unduly sensitive to sudden changes in temperature.

Basic Nature.

Magnesia is a typical base; it neutralizes all acids, with the formation of magnesium salts; when the acids are silica or clay some of the resultant salts are silicates. The complex silicates, when fused, form *basic slags*. Magnesite also neutralizes acids, with the formation of the corresponding salt and the evolution of carbon dioxide gas.

Plasticity.

Dead-burned magnesia is wholly devoid of plasticity, but can be made feebly plastic by mixing with it lightly calcined magnesia which has been ground extremely fine in water, so as to produce a colloidal material.

Shrinkage.

The great shrinkage which occurs when magnesia is heated has already been mentioned (p. 104). For this reason it is important that the material should be fully burned before it is made into bricks, etc. The shrinkage is least when the magnesite has been calcined, and partially fused in an electric furnace, such a product being richest in periclase.

Effect of Heat.

The first effect of heat on magnesite is to decompose it with evolution of carbon dioxide and the formation of a very light magnesia. On prolonged heating at a steadily increasing temperature the magnesia becomes more compact and eventually, if the temperature be sufficiently high, it is converted into the dense form which, on cooling, crystallizes as periclase. This change is accompanied by a marked increase in the specific gravity, which rises to 3.60–3.65. The periclase appears to be stable at all attainable temperatures.

Effect of Water.

Water has no effect in raw magnesite, but it gradually attacks magnesia, with the formation of the soluble magnesium hydroxide. The lightly calcined magnesia is the most readily attacked by water, but even the dead-burned material of maximum density is slowly attacked by water and more rapidly by steam. All forms of magnesite and magnesia are soluble in acids.

Specific Gravity.

- The specific gravities of the various forms of magnesite and magnesia are shown on p. 44

DOLOMITE

Dolomite is a double carbonate produced by the crystallization of a mixture of calcium and magnesium carbonates. It contains about 45 per cent of

magnesium carbonate and 54 per cent of calcium carbonate. The material commonly spoken of as "dolomite" in this country, is not a true dolomite but a magnesian limestone, and consists of an irregular mixture of magnesium and calcium carbonates with only a very small proportion of the double carbonate in definitely crystalline form.

Dolomite is less valuable than magnesite as a refractory material, as the lime in it is objectionable and reduces its durability. Dolomite and magnesian limestones are, however, largely used for lining steel furnaces on account of their being so much cheaper, in first cost, than magnesite. As they are less resistant the more expensive dead-burned magnesite (if properly prepared) is actually the cheaper in the end.

CHROMITE

Chromite is the mineral form of chromium oxide, but the pure material is never used for refractory purposes as chromé iron ore is much cheaper and quite satisfactory. The Norwegian ore containing 40 per cent of chromium oxide and not more than 6 per cent of silica is chiefly used.

Chromite is so inert that it acts as a neutral material (see *Chromite Bricks*, p. 50). Chromite has a specific gravity of about 4.5 and a refractoriness greater than Cone 42 (i.e. over 2000° C.).

GRAPHITE

Graphite or plumbago is a form of carbon which occurs as a mineral. The Ceylon graphite is preferred as a refractory material.

It should be carefully selected as to be free from obvious impurities. Pure graphite consists wholly of carbon but the commercial material seldom contains more than 98 per cent of carbon. It should be crushed to a moderately fine powder but not excessively fine; that which passes readily through a 40-mesh sieve, but is free from much "dust," is usually satisfactory. Graphite which is too coarse produces weak and porous crucibles; graphite dust makes the crucibles too dense so that they are liable to crack when lifted out of the furnace.

Refractoriness.

Pure graphite is quite infusible, and the commercial material is quite unaffected by any temperature attainable on a large scale provided air is absent. In an oxidizing atmosphere it burns away slowly without fusion.

Character.

Graphite is completely neutral to both acids and alkalis and is exceedingly inert. It can, however, exert a slight reducing action on metallic ores heated in contact with it. Graphite is slightly soluble in steel and in some other alloys.

Shrinkage.

Graphite is seldom used alone as a refractory material as it is devoid of plasticity. When mixed with fireclay it does not shrink appreciably, and therefore reduces the shrinkage of the clay with which it is mixed.

Effect of Heat.

In an oxidizing atmosphere, graphite or plumbago slowly burns away, but its rate of combustion is so small as not to be of serious importance. In a neutral or reducing atmosphere, pure graphite is quite unaffected.

Effect of Water.

Water has no effect on graphite, except in the event of freezing, when the expansion of the water, as it is converted into ice, tends to disintegrate large pieces of graphite.

Minor Properties.

Graphite is exceedingly soft, having a hardness of only about 1 on Mohs' scale; it has a high electrical conductivity.

COKE, LAMPBLACK AND CHARCOAL

Coke, lampblack and charcoal are occasionally used as substitutes for graphite in the manufacture of crucibles, but they are not desirable materials for this purpose. For further information on graphite and its substitutes see the author's *Refractory Materials; their Manufacture and Uses*.

CARBIDES

Various carbides have been suggested as suitable for the manufacture of refractory articles. The one most extensively used for this purpose is silicon carbide—more commonly known as carborundum—

which is made by heating a mixture of sand and coke in an electric furnace, when the carborundum forms one of the products. It does not occur in nature. Other carbides and carboxides are manufactured in a similar manner and are sold under various trade names.*

Carborundum is obtained as a mass of crystals almost black in colour and of intense hardness.

Refractoriness.

Carborundum is extremely refractory and is practically infusible. If heated in a current of air it decomposes, and its surface becomes covered with a film of fused silica. This must not be mistaken for a fusion of the material as a whole.

Chemical Composition.

Silicon carbide in its various forms corresponds very closely to the formula SiC , and contains 70 per cent of the element silicon and 30 per cent of carbon. Some of the other products formed at the same time contain a small proportion of oxygen, and are approximately represented by the formulae $\text{Si}_2\text{C}_3\text{O}$ or $\text{Si}_7\text{C}_8\text{O}$, or any intermediate composition.

Effect of Heat.

When heated in a current of air, carborundum is slowly decomposed, leaving a residue of silica, but if the temperature is sufficiently high for the silica to be fused a coating of this material is formed on

* See *Abrasive Materials*, by A. B. Searle Lth Pitman's Technical Primer Series," 2s. 6d. net).

the surface of the carborundum and any further decomposition takes place so slowly that the carborundum may be regarded as scarcely affected.

Other Properties.

Carborundum has a hardness of 9 on Mohs' scale, so that it is as hard as corundum and only less hard than the diamond. It does not shrink when heated, unless the conditions are such that it is gradually decomposed (p. 111). It is quite devoid of plasticity. Its thermal conductivity is intermediate between that of carbon and that of silica, hence it is useful for muffle-walls and other purposes where a good transmission of heat is required. Small crucibles for laboratory use made of carborundum are quite satisfactory for some ignition tests and ash-determinations. Like graphite, carborundum is largely inert and neutral. At high temperatures it is corroded slowly by sodium compounds and very quickly by red lead, but it is not appreciably affected by hydrofluoric acid.

CHAPTER IV

SHAPING THE WARE

THE manufacture of refractory articles follows certain general lines, quite apart from the nature of the raw materials used.* For example, all the refractory materials are first reduced to a moderately coarse powder, by means of powerful crushing and grinding machinery (Fig. 6); large pieces are removed by sieves and reground. The ground materials are then mixed together in suitable proportions, sufficient water being added to produce a paste of consistency suitable for the succeeding process. The mixing is usually effected in one or more pugmills (Fig. 7), which consist of a case containing a long shaft fitted with rotating blades or arms, which effect the mixing. The pugmills may be vertical or horizontal or one of each type may be used.

Pugmills tend to introduce air bubbles into the paste, and where this is objectionable, or where a more thorough mixing is required, an edge-runner or pan mill is used, which closely resembles a mortar-mill (see Fig. 8).*

Consistency of Paste.

* If the articles are to be shaped by hand or in plaster moulds, a soft plastic paste will be required, but if they are to be extruded from a machine, or

shaped in a power-driven press, a much stiffer paste is desirable.

The soft paste should usually be of such a

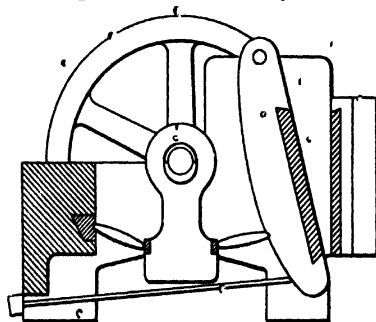


FIG. 6.—JAW-CRUSHER.
(Cross section.)

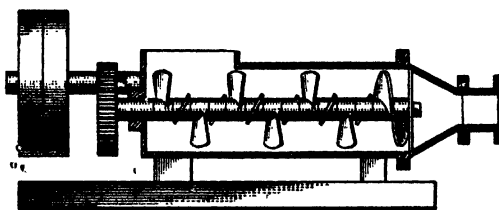


FIG. 7.—PUGMILL.
(Part section.)

consistency that when it is squeezed in the hand it retains a clear impression of the fine lines on the skin but does not adhere to the fingers. The consistency of the stiffer pastes must be adjusted to suit the particular machines in which they are used.

Hand-moulding.

Firebricks made by hand are still preferred by many furnace builders, who regard them as more durable than machine-made bricks. The mould (Fig. 9) consists of a frame of wood,* brass or iron,

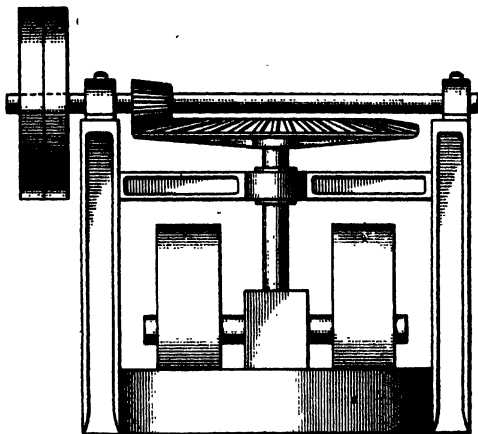


FIG. 8.—EDGE-RUNNER MILL.

which may be large enough to hold either one or two bricks. The moulder picks up sufficient paste to fill the mould completely, and throws the paste violently into the mould. He may then beat or "thwack" the mould with a flat non-shod wooden tool; cut off any surplus material with a wire, turn

* The wooden frame may be lined with any suitable metal to increase its durability.

the mould over, and deposit its contents either on a small board, or on the floor of the workshop.

The mould is then wetted or "dusted over" and is ready to be refilled.

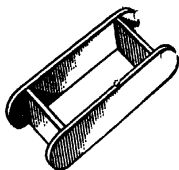


FIG. 9.—MOULD
FOR HAND-MADE
BRICKS.

This process is used, with slight modifications, for all kinds of firebricks, and for many of the larger blocks. It is simple, rapid and involves a minimum of capital expenditure. It requires far more skill

than is apparent at first sight and the work is, at all times, hard and strenuous, though much lighter with silica than with some clays. Where a large output is required, the moulder is usually provided with two assistants—a clot maker who prepares the mass of paste and shapes it roughly for the moulder, and a carry-off boy who takes the moulded bricks and deposits them on the floor.

Unless the moulder and his assistants are dexterous, the bricks may easily be misshapen or damaged.

Larger blocks are made in the same manner, but the mould is placed on the floor, and is filled gradually, each handful of paste being energetically pressed into position in such a manner

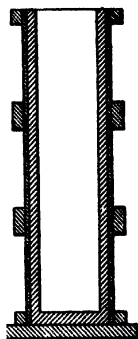


FIG. 10.
RETORT IN
MOULD.
(Sectional view.)

as to form a uniform mass, quite free from joints. A short time after the article has been made, the mould is either drawn away as a whole, or it is dismantled and the pieces removed separately. Wooden moulds are usually employed, but plaster ones are used for more elaborately shaped articles.

Retorts are made by lining a mould to the required thickness with the paste. As some retorts are very long the moulds are usually made in several pieces, as in Fig. 10, which shows a sectional view of a three-piece mould. The lowest part is lined first; the second piece is then bolted on to it and lined, after which the third portion is added and similarly lined. Sufficient time must be allowed to enable the paste to stiffen sufficiently before the second and subsequent parts of the mould are added. When the retort is sufficiently stiff to stand alone the mould is dismantled and the retort is allowed to dry slowly.

Machine Pressing.

A fairly stiff paste may be compressed to the desired shape in steel boxes or dies by means of mechanically-applied pressure. Various types of presses are employed, including screw-presses, toggle-lever presses, hydraulic presses, etc. In each case a plunger or "head" is brought into contact with the material, forces it into a box or die, and then applies a prearranged pressure. Bricks and other articles made in this manner appear to be more accurate in shape than those made by hand, but unless the refractory mixture is very carefully made

from skilfully selected materials the articles may be so dense to be durable. For this reason the pressure applied should not be more than is sufficient

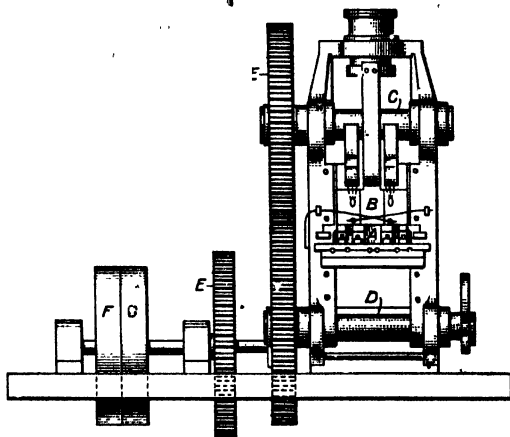


FIG. 11.—BRICK PRESS.

- A = Box or die, to receive article or mass to be pressed.
- B = Plunger, which applies the pressure in a downward direction.
- C = Toggle lever and shaft, causing movement of B.
- D = Shaft and mechanism, providing pressure in an upward direction from below.
- E = Gearing.
- F and G = Fast and loose pulleys.

to make articles of a good shape ; further compression may deteriorate instead of improving the article. Presses may be used for powdered materials in almost a dry state, but this is not usually desirable except for small articles. The presence of a little water acts as a lubricant, greatly facilitating the movement of the particles over each other when

subjected to pressure, and results in the production of stronger and more durable articles as well as greatly reducing the amount of power required.

A typical press of the toggle lever type is shown in Fig. 11. The material is placed in the box *A*, compressed by the plunger *B*, operated by the toggle levers on the shaft *C* which, in turn, is driven by the pulley *F*, through the gearing *E*. Simultaneously, an upward pressure is applied to the material through levers attached to the lower shaft *D*. The latter also raises the finished article from the box *A* and so facilitates its removal.

In the case of silica and other non-plastic or very feebly plastic materials, sufficient water should be added to give the mixture the consistency of "wet sand" similar to that which gives the best results in building "sand castles" at the seaside. Presses may be used for hollow ware as well as for solid articles. The small refractory parts of gas burners, electric radiators, etc., are usually made of a mixture of fireclay with asbestos, grog, or other non-plastic refractory materials, but some of them are made of highly complex mixtures. The various materials are dried, ground to powder, mixed in a dry or almost dry state, and then shaped by compression in fly-presses worked by hand. Sometimes it is possible to press a dozen or more of such articles at a time, by using a power-driven press. This method of shaping ensures great accuracy with regard to size and shape, which is so essential when a refractory part has to be screwed or cemented into an article of which it forms only a part.

Repressing.

* Articles made by hand-moulding are sometimes improved in shape by pressing them mechanically. This is known as "repressing." It has the disadvantage of destroying the original texture of the mass so that, although the shape is improved, the crushing strength is reduced—sometimes to a serious extent.

Extrusion.

A particularly convenient method for producing bricks and blocks without any "frog," also tubes, pipes, and some kinds of hollow blocks is that known as "extrusion." A mouthpiece or die of suitable shape is fitted to the outlet of a pugmill or similar machine, and the clay paste is forced through it in such a manner that the extruded mass has the form of a column of the desired width and thickness but of indefinite length. This column is then cut by a series of wires stretched on a frame and so produces a number of articles of the desired length. Thus, for fireclay bricks the opening in the mouthpiece is usually about $9\frac{1}{2}$ in. \times 5 in. (so as to allow for a shrinkage to 9 in. \times $4\frac{1}{2}$ in.), and the column is first cut into pieces about 2 ft. in length; each piece is then cut by a series of wires placed $2\frac{1}{2}$ in. or $3\frac{1}{2}$ in. apart on a frame. Eight or ten bricks are thus produced by one movement of the cutting device.

The type of machine usually employed is shown in Fig. 12. The clay or plastic mixture is supplied to the crushing rolls *A*, which crush it into thin

• sheets and deliver it to the trough mixer *B*, below. The paste is there mixed with water (if necessary) and passed into the pugmill *C*, where it is mixed still more thoroughly and is then passed through the collar or extension *D*, into the mouthpiece *E*, where it is converted into a column of the desired

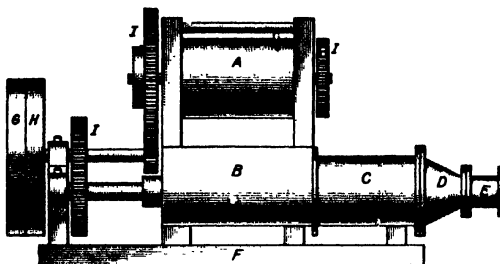


FIG. 12.—WIRE-CUT BRICKMAKING MACHINE.

- A* = One of a pair of crushing rolls.
- B* = Open mixer, containing revolving knives.
- C* = Closed mixer or pugmill.
- D* = Collar, connecting *C* and *E*.
- E* = Mouthpiece or die, which shapes the clay.
- F* = Frame of machine.
- G, H* = Fast and loose pulleys.
- I* = Gearing.

shape. As the material passes out of *E*, it is cut off by wires into pieces of the required size.

This process is simple, cheap and effective; it requires a material of moderate plasticity and so is not applicable to silica bricks. It is commonly known as the *Wire-cut Process* of making bricks, etc.

Jollying and Jiggering.

When hollow-ware articles are made in large quantities it is often convenient to use a jigger or

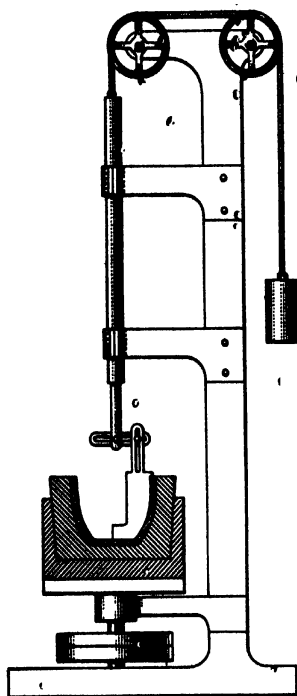


FIG. 13.—JOLLEY, MAKING CRUCIBLE.

(Mould shown in section.)

jolley (Fig 13). In that case, a plaster mould is mounted on a vertical revolving spindle beneath a vertical or inclined holder carrying a "profile" or shaping tool. A mass of paste is placed in the mould which is then rotated at a suitable speed, and the profile-tool is gently lowered on to the paste, a moderate pressure being applied. The paste is displaced by the profile and flows towards the mould, so that in the course of a few seconds it has assumed an external shape corresponding to that of the mould, and an internal shape

corresponding to the profile. As soon as the paste ceases to move, the profile is released and rises out of the way, any surplus paste is cut off with a knife

and the mould with its contents is taken to the drying stove.

This method is specially suitable for crucibles and other hollow ware with a symmetrical interior as well as for discs, plates, lids, knobs and a considerable variety of other articles.

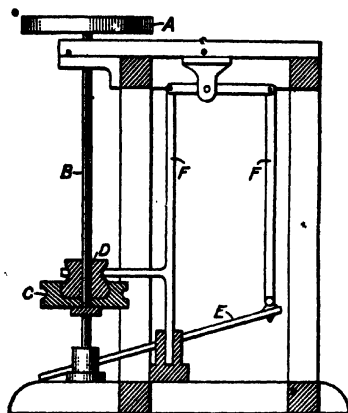


FIG. 14.—POTTER'S WHEEL.

- A = Rotating table or wheel.
- B = Spindle, carrying the wheel.
- C = Driving pulley.
- D = Friction clutch, connecting B and C.
- E = Treadle, operating levers F, and clutch D.
- F = System of levers forming a regulator for speed of clutch D.

Throwing.

One of the earliest methods of working plastic materials is that known as "throwing" on a potter's wheel (Fig. 14). In the manufacture of refractory materials this process is mainly confined to crucibles

and lids, and has largely been displaced by jollying, or pressing, which processes are quicker and require less skill.

When "throwing" a crucible, the potter places a mass of paste on a revolving table (which he terms the "wheel") and by manipulating the rotating parts with his hands he presses and draws it to the required shape. Small guides or indicators mounted on a stand near the "wheel" enable him to judge with sufficient accuracy whether the article is correct in size. The finished article is cut from the surplus paste by means of a wire and removed.

Though apparently one of the simplest of processes throwing requires a great amount of skill; hence its displacement by other methods.

Hand-modelling.

Large pieces of special shape, such as tank blocks, retorts and the large "pots" used for melting glass are usually shaped by hand. Pieces of paste are pressed forcibly on one another until the article is produced in a crude form and it is afterwards scraped or "tooled" to make it precisely of the desired shape. In some cases, only a small portion of the article can be "built up" at a time; it must then be allowed to stiffen before the next quantity of paste is added. In this way a week or more may be required to make some goods.

Considerable skill and ingenuity are required in modelling refractory articles by hand; the shaping is not, in itself, difficult but the precautions which must be taken to make the material homogeneous,

and to balance the thickness of the various parts so as to avoid cracks during manufacture or use, call for conscientious and skilled workmanship.

Casting.

When a material consists of small particles which are capable of suspension in water, or in a very dilute solution of soda or caustic alkali, such a suspension (commonly known as a "slip") may be used for "casting." For this purpose, a plaster mould of suitable shape is filled with the prepared slip and allowed to stand for a length of time which must be ascertained by trial. The superfluous slip is then poured out and the mould with its contents set aside to dry. As the plaster mould is absorbent it withdraws water from the slip, leaving a deposit of solid material uniformly distributed over the interior surface of the mould, so that when the superfluous slip is poured off a perfectly shaped article remains in the mould, and can be removed when sufficiently dry.

This process is applicable to non-plastic as well as to plastic materials, provided that a suitable suspension can be obtained. This is usually the case when the substance can be partially converted into a colloidal form, such as is produced by prolonged grinding in water. When a plastic material, such as clay, is one of the ingredients of the slip, the casting process is greatly facilitated. Thus, mixtures consisting of a large proportion of grog (p. 89) with a small proportion of fireclay, have for many years been used for casting large crucibles, and for

the still larger "pots," used for melting glass (Fig. 4, p. 67).

Glass-working Methods.

The methods of working which are mainly confined to the glass industries, have been used with great success in the shaping of vessels made of fused quartz. A little of the fused material is taken on to the end of a pontil or blowing tube, into which compressed air is then admitted. As a result, the fused quartz is gradually converted into a large "bubble" which, when cold, may be cut into discs or plates, or the "bubbles" may be drawn into tubes, or made into flasks, etc. If a suitable mould is used, the "bubbles" may be blown therein so that the articles have the shape of the mould.

Alternatively, articles of fused quartz may be laboriously built up by fusing pieces of the material together.

Great manipulative skill is necessary in the shaping of fused quartz and, at present, very few men have the necessary ability to make such ware. Those who are able to do so show remarkable dexterity and ingenuity, and when the refractoriness of the material is considered some of the ware made of fused quartz is really remarkable.

CHAPTER V

DRYING

MOST articles made of refractory materials can be dried without much difficulty, provided that the temperature is not raised too rapidly and that all "draughts" are avoided. On the other hand, very large articles, such as the "pots" used for melting glass, retorts, etc., require very great care.

Effective drying may be based on either of two principles—

(1) The articles may be placed in a chamber where they will not be exposed to draughts, but where there is sufficient ventilation to dry them completely (see Fig. 15). The temperature may be raised so slowly—particularly at first—that there is no danger of cracking, and the goods may be removed when they are dry. This method is effective, but very slow; it may be hastened by using a tunnel-shaped chamber (Fig. 16) through which a slow current of air of suitable temperature is drawn continuously, the volume of air and its temperature being carefully regulated so as not to damage the goods. Such tunnel-dryers require very large outputs in order that they may be worked economically, but if well designed they are quite satisfactory. For medium and small outputs the drying chamber usually consists of a large shed, the floor of which is hollow and heated by steam, fires, or waste gases from the kila and boiler. Such hot-floor dryers are wasteful

in heat, and somewhat irregular in action but, on the whole, they are quite satisfactory where the output does not justify a more efficient but more expensive type of dryer.

(2) The articles may be placed in an airtight chamber in which they are heated rapidly to a temperature of about 190° F. (87.5° C.), the atmosphere in the chamber being, meanwhile, kept fully

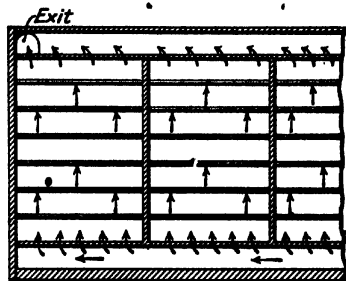


FIG. 15.—CUPBOARD TYPE OF DRYER.
(Cross Section.)

saturated with moisture, by the injection of steam. The hot saturated air must be maintained in a constant state of circulation, so as to heat every part of the chamber and its contents quite uniformly, and without any risk of surface-drying. This can only be assured by the use of devices which control the humidity and temperature automatically, and by a well-designed system of air-circulation.

When the goods have been heated *throughout* to the desired temperature, the saturated air is gradually replaced by air at the same temperature but

with a lesser proportion of water. This unsaturated air immediately takes up water from the goods, drying them rapidly, yet safely as, with proper control, no hardening of the surface of the goods can occur until all the moisture has been removed from their interiors.

By this means, the rate of drying may be rapid without risk of cracking, and the greatest possible economy may be effected in the fuel used.

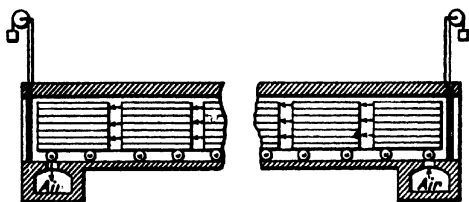


FIG. 16.—TUNNEL DRYER.
(Cross section.)

If bricks or other articles are heated rapidly in an open chamber, their surfaces will dry more quickly than the interior and will harden. A little later the pressure of the water-vapour inside the goods will become so great—because it cannot escape gradually through the hardened surface—that eventually it will exceed the resistance of the surface of the material, which will then crack and allow the water-vapour to escape. This cracking may be avoided by keeping the surface soft (with a saturated atmosphere) until all the pressure in the interior of the goods has been released, or the rate

of heating may be reduced so much that no appreciable pressure is developed.

Whilst it is obvious that the use of a saturated atmosphere and rapid heating is preferable to the slower method of heating, the former is only used to a very limited extent, partly on account of its comparative novelty to manufacturers of refractory materials (though it has long been used in other industries), and partly because of the greater capital cost involved. Wherever it has been installed, however, it has proved more economical than other methods.

Placing in the Dryer.

The goods in hot-floor dryers are placed directly on the floor, or they may be stacked on the floor, or they may be stacked one above another with a small space between each (*see* Fig. 15). In tunnel dryers (Fig. 16) the goods are usually placed on cars or trucks, each car being fitted with loose shelves. In the "saturated atmosphere" method the goods are placed in precisely the same manner as in other forms of dryer, cars or trucks being preferable as they avoid the necessity of men entering the kiln.

Hollow-Ware

The methods just mentioned are equally applicable to hollow-ware, but it is sometimes more convenient to use some modification. Thus, for a moderate output of crucibles, it is better to arrange sets of latticed shelves in the drying-room, and to run grids or steam pipes below the shelves instead of

heating the floor. In most of the larger steel works the crucibles are dried on ordinary shelves on the walls of the furnace room, no special precaution being taken.

Glasshouse pots and large retorts are usually dried extremely slowly, from three to six months often being occupied in the drying.

The subject of drying refractory articles in an economical and rapid manner is so complex that it cannot be adequately dealt with in a short chapter. The important underlying principles have been given above, but readers requiring more information should see the author's *Refractory Materials ; their Manufacture and Uses.*

CHAPTER VI

BURNING REFRACTORY ARTICLES

THE process of "burning" or "firing" refractory articles has for its object the conversion of the soft and friable article into one possessing great crushing strength, resistance to the highest temperature to which it will be exposed when in use and to such corrosive and abrasive actions as may be required.

Definition.

The term "burning" is somewhat of a misnomer, as the material does not evolve heat like a fuel or other combustible material. The term "firing," whilst better in some respects, is also inadequate, and unduly reminiscent of other uses of the same term. The word "baking" is occasionally used, but is usually restricted to temperatures below a red heat, so that it has become customary to describe a brick as "baked" when it has not been sufficiently heated.

The term "heating" would appear to be the least objectionable, but "burning" has become so well established that its use is likely to be continued.

In the sense in which the term "burning" is used by manufacturers of refractory articles and materials, it refers to heating to a temperature sufficiently high, and maintained for a sufficiently long period to effect the desired changes in the

material. If these changes have not progressed sufficiently, owing to the temperature being too low or the time of heating too short, the products will be "under-burned"; if the heating has been excessive the products will be "over-burned," though the latter can scarcely occur with refractory materials.

The burning process is largely the same for all refractory materials, but differences are made with regard to details according to the nature of the refractory material, and the purpose for which it is to be used. In each case, the articles are placed in a kiln in which they are heated somewhat slowly to a prearranged temperature. They are maintained at this temperature, or slightly above it, for a period which depends on the nature of the material, and are then allowed to cool slowly. The burning is then finished and the articles may be removed from the kiln.

Described in this manner the process appears to be exceedingly simple, as indeed it would be, were only low temperatures to be attained. Refractory materials must, by their very nature, be fired at very high temperatures, and it is in connection therewith that the chief difficulties arise.

Kilns.

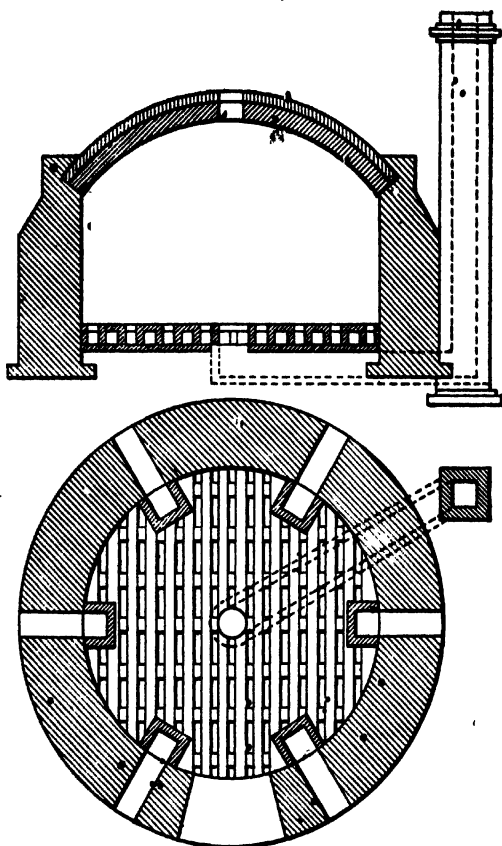
The kilns used for burning refractory materials are of seven kinds—

(1) *Shaft kilns* resemble a lime kiln, or a stout chimney, in general form. The materials are fed in, at or near the top of the shaft, and gradually

descend downwards, becoming hotter in their descent. When removed from the bottom of the kiln the materials should be completely burned. The heating is effected by coal-fires or by producer gas-burners on the periphery of the kiln, the air required for combustion being drawn from the base of the shaft and heated by passing it through the burned material. The flames and kiln gases mix with the refractory material in the upper two-thirds of the shaft, and thereby effect the necessary burning of the refractory material. Shaft kilns can only be used where the shape of the product is unimportant, as in burning fireclay to produce grog, or in the dead-burning of magnesia. The temperature attained depends on the design of the kiln, and the fuel used. Coal-fired shaft kilns seldom attain a temperature exceeding 1300°C . at their centre, but with producer gas and the aid of regenerators for both gas and air, temperatures exceeding 1800°C . have been regularly used on the Continent.

Shaft kilns are usually continuous in action, but intermittent shaft kilns are sometimes used.

(2) *Down-draught kilns or ovens* may be either circular or rectangular, the former being cheaper to erect and of stronger construction, but the latter are more convenient for bricks. Many patterns of down-draught kilns are in use for different purposes, but for refractory articles this type of kiln should be provided with a perforated floor, with flues beneath it leading to a collector or "well" which, in turn, discharges into the main flue leading to the chimney (see Fig. 17). In some works, firebricks



• FIG. 17.—ROUND DOWN-DRAUGHT KILN.
(Section and plan.)

are burned in down-draught kilns with solid floors and no flues above the well, but such a construction is not the best.

The flames and gases from the fireplaces, or gas-burners in the walls of the kiln, rise up to the crown, and are thence deflected downwards among the goods. The crown should be curved and of such a shape as to ensure this direct downward deflection, or the kiln will not be heated uniformly. Unless the shape of the crown of the kiln is correct a large amount of fuel is wasted unnecessarily.

The down-going gases are baffled by the goods in the kiln, and are consequently distributed among the articles to be burned, thereby heating them before the gases pass into the flues and away to the chimney. As it is essential that all the goods should be subjected to the same heat-treatment, it is of the greatest importance that the flames and gases should be distributed uniformly throughout the kiln. With reasonable care and skill, remarkably uniform heating can be secured in down-draught kilns, and for this reason this is often the most satisfactory type of kiln for refractory articles. It is equally suitable for almost every kind of article and is used for bricks, retorts, pipes, crucibles, etc., with complete satisfaction so far as the quality of the goods is concerned.

Like all single or intermittent kilns, those of the down-draught type are wasteful in fuel as the gases pass out of the kiln at a temperature very little lower than that of the goods. By passing these gases into a series of other kilns, from half to

three-quarters of the fuel may be saved (see *Continuous Kilns*, p. 138).

(3) *Newcastle kilns* (Fig. 18) consist of a rectangular chamber with a curved crown. The fireplaces are at one or both ends of the kiln, and the flues either at the end opposite the fire or in the middle

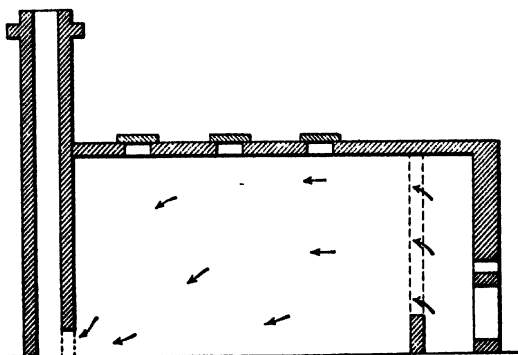


FIG. 18.—NEWCASTLE KILN.

(Vertical section.)

of the side walls of the kiln. The flames and hot gases pass chiefly in a horizontal direction through the goods, and great skill is needed to heat the goods nearest the flues without overheating those nearest the fire. Complete uniformity of heating is impossible in Newcastle kilns, but so skilful are some firemen that the articles are burned sufficiently uniformly for all practical purposes.

Newcastle kilns, like down-draught ones, are

wasteful in fuel; much of this waste may be prevented by connecting them in series.

(4) *Continuous kilns* are so named because they are worked continuously. The best known type of continuous kiln is that designed by F. Hoffman, and afterwards modified in various ways. The most convenient form for firebricks consists of two parallel

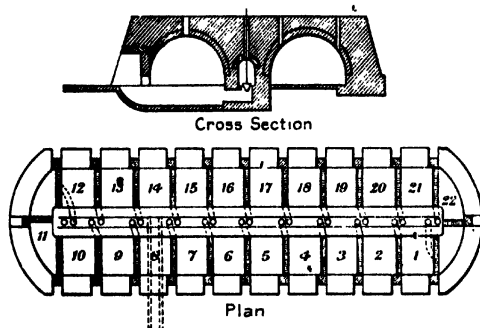


FIG. 10.—CONTINUOUS KILN.

("Belgian" type with grates.)

Structures, each about 120 ft. in length (Fig. 19), with a main flue in the wall between them, or else surrounding the whole kiln. These structures are connected at each end by a large flue, and entrances or "wickets" are arranged in the side walls, about 8, 10, or 14 ft. apart, according to the size of the kiln or the temperature to be attained. As a matter of convenience each "wicket" is presumed to lead to a separate chamber, the kiln being imagined to

be divided into 12 to 24, or more "chambers," according to its size. No actual division walls are necessary, yet the kiln is operated as though they existed.

In some kilns there are actual division walls of brickwork so as to provide means for working each "chamber" separately from the rest if required. This is important for terra-cotta and for very plastic clays, and for articles which have to be fired very slowly. These are conveniently known as *continuous chamber-kilns*. Those built on the down-draught principle are particularly valuable for high-class refractory articles, such as retorts, crucibles, etc., when the output of the works justifies their erection. For firebricks, a simpler type of continuous kiln is sufficient.

In a simple continuous kiln, of a pattern suitable for refractory articles, the fuel is burned on a grate placed transversely at the end of each "chamber," usually a little to the right of the wicket. The fuel may be fed through an opening in the side of the kiln, or through smaller openings in the crown. Air is admitted through the grate-bars, its volume being controlled by a simple slide or damper, but the greater part of the air enters through the wickets in the empty chambers and passes through the cooling bricks along the interior of the kiln.

The flames and gases pass chiefly in a horizontal direction through the chamber to be heated, and then through a flue in the wall of the kiln to the main or chimney-flue. Owing to the shape of the kiln, these gases travel a distance of from 40 to 84 ft.

along goods to be heated, before they pass to the chimney. By this means the temperature of the gases is reduced to such an extent that the heat left in them is only just sufficient to carry them up the chimney and they have no further value for heating purposes. In a badly designed or improperly managed kiln, the gases escape at a higher temperature, with a correspondingly great loss of heat and wastage of fuel.

When the goods in one "chamber" are completely burned, another "chamber" containing freshly-set goods is brought into the "round" of the kiln by closing the damper in the flue which previously admitted the gases to the chimney and opening the corresponding damper in the next chamber.

By this means, the fire is made to travel gradually around the kiln at the rate of about one "chamber" per day, gradually heating the goods and afterwards cooling them by the air drawn through them, prior to its being used for the combustion of the fuel.

When properly designed and skilfully operated, a continuous kiln of this type requires only from one-quarter to one-half the fuel needed by separate kilns with chambers of the same capacity.

A continuous kiln of the type just described is a large and expensive structure, so that there is always a temptation to reduce its size to a minimum. This desire for economy often leads to the erection of kilns which are too short to be efficient, so that the saving in cost of erection is more than counter-balanced by the greater quantity of fuel required.

To secure the maximum efficiency with refractory goods to be finished at a temperature of 1400°C ., it is necessary that the total length of the "chambers" should not be less than 280 ft. It is almost immaterial whether this is divided into 20 chambers of 14 ft. each, 16 chambers of $17\frac{1}{2}$ ft. each, 28 chambers of 10 ft. each or in any other manner. This great length is needed in order to make full use of the heat in the flames and kiln gases, and to cool the goods effectively and without cracking them. The figure of 280 ft. may be taken as a minimum for fireclay goods; but silica and magnesite goods—which require a slower cooling—should be provided with a greater length of kiln.

If, as is usually the case, a shorter kiln is employed—some have only 12 chambers each 8 ft. in length, or 96 ft. in all—there will be a great waste of fuel due to the escape of gases at too high a temperature, and to the inability to use all the hot air required to cool the bricks. This loss can only be prevented by adding an appropriate number of "chambers" to the existing kilns—a process which is by no means difficult if the brickwork is in good condition.

• Continuous kilns of the type described (as distinct from continuous chamber-kilns, p. 139) are excellent for firebricks of all kinds. They are not so suitable for hollowware as are kilns worked on the down-draught principle; but if the latter form part of a continuous-chamber kiln they are remarkably efficient.

• (5) *Tunnel kilns* or *car kilns* consist of a tunnel which should be at least 280 ft. in length (preferably

320 to 350 ft.), through which the goods to be burned are carried on cars or trucks each 4 to 5 ft. in length as shown in Fig. 29.

In a well-designed tunnel kiln, firebricks, crucibles and other articles of moderate size can be fired and cooled at the rate of one truck-load per hour; this, in a kiln 300 ft. long, is equivalent to a total firing and cooling time of about three days as compared with 18 to 24 days in a continuous kiln of the Hoffman type. This remarkable difference is partly due to the much smaller capacity of the cars, but is chiefly owing to the fact that in a tunnel kiln each part of the structure remains at a constant temperature, whereas in the other type of continuous kiln each part of the structure has to be heated and cooled in turn.

The tunnel kiln has not been used extensively for firebricks, but the author has employed one successfully for the supply of all the firebricks required in a large pottery—the chief use of the kiln being for firing pottery ware—and has satisfied himself, as a result of trials in other works that a properly designed tunnel kiln, is one of the most efficient and economical kilns for refractory materials. When failures arise, it is usually due to the kiln being much too short or to ignorance of the proper methods of applying the heat.

Tunnel kilns are usually gas-fired, as this affords the best means of maintaining a constant temperature with a minimum of effort.

The goods to be fired are placed in cars which enter at one end of the tunnel and pass forward,

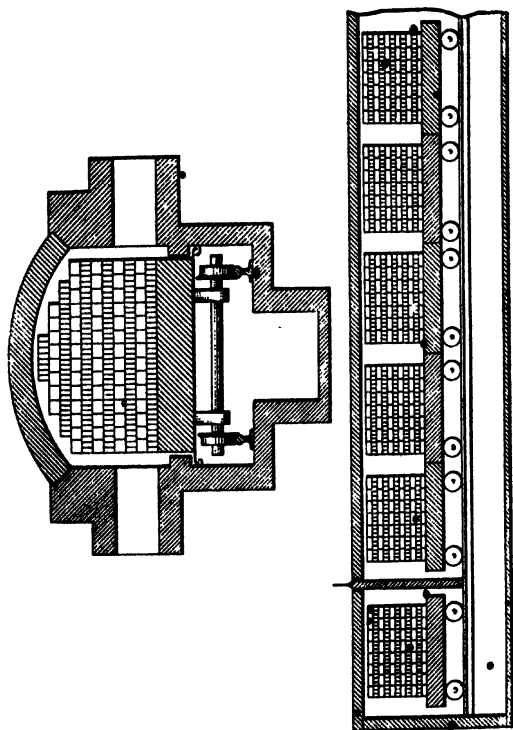


FIG. 20.—TUNNEL KILN.
(Cross section and longitudinal section.)

either continuously or at intervals of an hour or so, until they eventually pass out burned and relatively cool from the other end of the tunnel. The process of burning is extremely simple, because each part of the kiln is kept at a prearranged temperature, whereas in all other kilns the temperature of the kiln, as well as that of the goods, has first to be raised and afterwards to be lowered in a skilful manner.

Apart from this, the mode of heating in a tunnel kiln is similar to that in a Hoffman continuous kiln; in both, the goods are gradually heated by the "waste gases," and are cooled by air which is thereby heated and afterwards used for burning the fuel.

The chief drawbacks to tunnel kilns are: (i) the very large quantity of material which is required to keep them fully at work (they are not satisfactory when working much below their normal output); (ii) the great cost of the cars on which the goods are carried through the kiln; and (iii) the impossibility of "steaming" or "water-smoking" the goods independently of the general heating. The first-named objection is very serious with some refractory materials, and though it could be overcome by suitably modifying the kiln, no such modification has yet been made in any existing tunnel kiln.

In the Dressler tunnel kiln, the gases are confined to long heat-ducts or flues of a special shape, so that the contents of the kiln are protected from the direct action of the flames. In this kiln, the

articles may be placed on shelves on the cars—a procedure which greatly facilitates the loading and emptying of the kiln.

The fuel consumption of a tunnel kiln is almost the same as that of the Hoffmann continuous kiln. The tunnel kiln ought to be more economical in

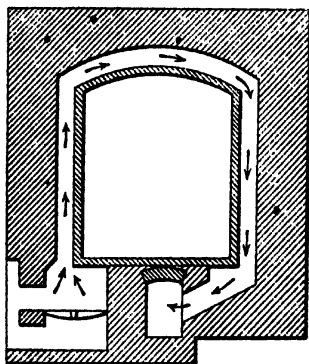


FIG. 21.—MUFFLE KILN.

(Cross section.)

fuel, but any advantage gained is usually lost as a result of poorly designed details, or lack of skill in management.

(6) *Muffle kilns* (Fig. 21) are employed when the goods must be heated with extreme slowness, and when they must be protected from direct contact with the kiln gases. They are seldom used for refractory materials, though occasionally employed for very large crucibles and for ware of a highly

specialized nature. Most refractory articles which have to be protected from kiln gases are more economically fired in saggers than in muffles or, if the output is sufficiently large, a Dressler-tunnel kiln (p. 144) will be found very satisfactory.

(7) *Rotary kilns* have also been used for burning lumps of refractory material.

Gas- and Coal-Firing.

For the highest attainable temperatures, gas-firing is superior to coal burnt direct in the kiln-mouths. To be effective, a gas producer must be kept constantly at work, which necessitates the use of either a continuous kiln or a sufficiently large number of intermittent kilns.

For many purposes, semi-gas firing is preferable to the use of a producer. In this method the heating is commenced with an ordinary coal fire, but this is gradually converted into a producer, so that the heating is finished with gas-firing. Semi-gas firing is particularly suitable for small intermittent kilns which have to be heated to a high temperature.

Gas-firing is not more economical than coal when burning refractory materials, but it enables the heating to be controlled more completely. It necessitates the employment of at least two skilled men—one at the producer and one at the kiln—whereas with coal-firing one man will suffice. The impression that gas producers are almost automatic does not apply to those used for firing refractory materials; on the contrary, unless the producer is

- under the charge of a skilled man trouble is certain to ensue.

Recuperators and Regenerators.

- Most manufacturers of refractory materials who use intermittent kilns fail to make sufficient use of the waste gases which pass to the chimney. If these gases are first passed through a regenerator, or preferably through a recuperator, most of the heat can be utilized.

A recuperator consists essentially of a series of tubes in a brickwork chamber; the hot gases from the kiln pass through the chamber in one direction, whilst the air is drawn through the tubes in the opposite direction and is heated without being contaminated by the gases. This hot air may be used to improve the combustion of the coal or gas in the kilns or it may be employed for drying the goods.

Recuperators and regenerators cannot be applied to continuous kilns because, in these, the freshly-set goods are heated by the "waste" gases, and the cooling goods act as a regenerator and heat the air required for combustion.

Fans v. Chimney-draught.

- Intermittent or single kilns which are not fitted with recuperators or regenerators, must have a chimney to create the necessary draught on account of the heat of the gases, but other kilns can be worked far more reliably if provided with a fan. The difference in the draught is readily seen if a recording draught gauge is used, particularly in stormy

weather. Most manufacturers of refractory materials are still afraid of fans, alleging that they are likely to fail at any time and that they do not produce a satisfactory draught. The risk of failure can always be avoided by having a spare fan (or usually, spare parts will suffice), and when defects in fan-draught occur they will generally be found to be due to either too small a fan, or to using a rapidly-running instead of a slower-moving fan. A suitable fan will enable more heat to be taken out of the kiln gases and used, and will provide a steady draught—two advantages which more than compensate for the cost of running and repairs.

Starting the Burning.

The burning of refractory materials—no matter which type of kiln is used—is commenced by applying a very gentle heat to the goods. In some instances a small, smoky fire is lighted and kept smouldering until the contents of the kiln are warmed throughout to a temperature of a little above the boiling point of water—say 250° F. or 120° C. This temperature is not exceeded until the contents of the kiln or chamber are completely dry.

During this period a considerable amount of water is evolved as steam; about 1 cwt. of water per ton of goods being by no means unusual. As this amount of water produced about 3,000 cu. ft. of steam, which must be removed without damaging the bricks, it is obvious that great care will be necessary and that ample ventilation must be provided.

Unless the water is all removed sufficiently early in the burning, it will cause trouble later, and may even prevent the goods from being properly burned. A skilled burner can at once identify goods which have suffered in this way, and will describe them as "steamed."

Decomposing the Clay.

As soon as the mixture has been completely freed from moisture, the fireman proceeds to decompose the clay in the goods if any clay is present; otherwise, he raises the temperature of the kiln as steadily as possible. The decomposition of the clay is effected at from 500 to 900° C—at a temperature known as "black-red to red"—and in raising the temperature of the kiln for this purpose great care is required to ensure uniformity. If any part of the kiln is heated too rapidly, the goods therein may crack or fall to pieces, because the decomposition of the clay is accompanied by a great evolution of water (the so-called "combined water"). If the temperature rises steadily and not too rapidly this part of the burning is one of the least difficult.

• At the same time as the clay is decomposed, various other changes occur. The conversion of any silica (quartz) begins; any vegetable matter commences to decompose and some of it may even begin to burn like fuel. Any limestone or magnesite is converted into quicklime or magnesia respectively, and many other changes of lesser importance occur in the small quantities of other minerals which may be present.

All these changes occur in a normal and proper manner, so long as there is an ample supply of air in the kiln, and the temperature is raised sufficiently steadily. Irregular heating—especially if associated with insufficient air—causes the formation of dark cores, bloated shapes and other defects.

During this part of the burning, the clay and any raw magnesia begin to shrink and the silica to expand, but these changes do not concern the burner until a later period in the firing.

It is not usual to draw any test-pieces or trials at this stage unless the goods are particularly liable to form black cores. In that case, trials should be drawn and broken, and examined at intervals of a few hours and the temperature should not be allowed to exceed about 900° C. (a dullish red heat), until all the dark core-forming material has been burned away.

Silica, bauxite and magnesite bricks cause little or no trouble at this stage, but some fireclay bricks cause much anxiety.

Full-Fire.

As soon as the contents of the kiln are at a bright red heat and all danger of cores and blotting is passed, the fires are cleaned and fired more vigorously or more gas is turned on and the rate of heating is increased. Within reasonable limits, the heating may now be fairly rapid, provided it is well under control.

The most interesting changes now occur, and trials drawn from the kiln at four-hourly intervals

should show the progress of these changes. One of the most noticeable is the gradual hardening of the material which, having attained its highest degree of porosity, rapidly loses some of it as the burning progresses. Under a microscope the gradual fusion of some of the materials may be observed, the impurities commencing to fuse first—after a preliminary combination with some of the other constituents, and the formation of complex silicates, etc. The proportion of fused material increases comparatively slowly, and as it is all absorbed in the interstices or voids of the material, there are no signs of fusion obvious to the unaided eye until a much later stage is reached. With most refractory materials, the heating is stopped long before any striking signs of fusion develop.

What appears to take place during the full-fire period is as follows—

(a) The more fusible constituents, including any complex silicates, etc., previously formed, begin to fuse and the molten, slag-like material is absorbed in the pores of the goods.

In the case of silica bricks, the lime added as a bond should, at this stage, have been converted wholly into calcium silicate which should gradually melt to a thin, clear glass readily absorbed by the pores.

In the case of magnesia bricks containing iron, the latter should have been reduced, forming a complex fusible ferrous silicate which should gradually melt and fill the pores.

In fireclay bricks the small proportion of glassy

material is due to the combination of the soda, potash, lime, magnesia and iron with the decomposed clay.

(b) This molten material becomes increasingly corrosive as the temperature rises, and it attacks the unfused material forming still more complex silicates, etc. The smaller the particles of fusible materials, the more rapidly will they melt, so that by grinding a portion of such material (or those which form it) to extraordinary fineness the amount of fused material at any given temperature can be increased.

In the presence of an increasing amount of fused material the strength of the articles is gradually reduced, so that at 1350° C. bricks cannot withstand a pressure of 50 lb. per sq. in. On allowing them to cool to a lower temperature, the fused material solidifies, binding the remaining materials very firmly and forming a very strong product.

As the amount of fused material increases, the unfused "skeleton" diminishes, so that if the firing were continued sufficiently long at a sufficiently high temperature, the unfused "skeleton" would not be strong enough to enable the refractory article to retain its shape, and distortion or warpage would occur; under still more severe conditions of heating the article would lose its shape completely. Actually, the heating is, of course, stopped before any distortion occurs.

(c) Any clay present shrinks—partly as a result of a reduction in the size of the individual particles, and partly as a result of partial fusion. If the heating be prolonged at a sufficiently high temperature

(1300° C. or above), sillimanite is formed and produces a felted mass of crystals on cooling.

The remainder of the clay forms an amorphous mass, some of the pores of which are occupied by the fused material.

(d) Any free silica present is partially converted into cristobalite or tridymite, the amount so formed depending on the smallness of the particles, the temperature attained, and the duration of the heating. The aim of the manufacturer should be to secure as much conversion as possible, as the articles thereby attain their maximum stability at high temperatures. The expansion of the silica occurs at the same time as its conversion.

(e) Any free alumina (bauxite) present gradually increases in density, with a corresponding shrinkage, but—apart from the very small quantity which may combine with any other metallic oxides to form aluminates—no change occurs.

(f) Any magnesia present is gradually but very slowly converted into periclase (p. 45). In most cases, the greater part of the magnesia remains in a shrunk amorphous form corresponding more or less completely with "dead-burned" magnesia.

A little magnesium silicate may be formed by the combination of magnesia and silica, this silicate is fusible but is much more viscous than the calcium, sodium, and potassium silicates and it is not so corrosive.

(g) Any iron compounds present are almost invariably reduced to the ferrous state and form complex ferrous silicates. In the case of magnesia

bricks, a fusible spinel, composed of magnesia and iron oxide, is formed in variable proportions,

(h) Numerous other changes occur among the various minerals present, but they are of minor general interest.

Soaking in Heat.

The rate at which heat penetrates to the interior of refractory materials, is so low that it is not sufficient merely to raise the kiln to a definite temperature; the articles must be maintained at that temperature, or slowly raised to a slightly higher temperature, until they are uniformly heated throughout. This is known as "soaking them in heat." The changes which have proceeded very slowly at a lower temperature do so with greater rapidity during the soaking, and a great general improvement in the quality of the goods is thereby produced. For this reason, prolonged "soaking" is very important, notwithstanding its costliness. In the case of silica and magnesia bricks it is of the highest importance, and even fireclay bricks of the best quality are greatly improved by it.

Considerable time is required for the "soaking" to be effective, but the cost of maintaining it for a longer period than 48 hours is usually considered to be prohibitive. This is largely due to the use of intermittent kilns; the cost of fuel is less serious in a continuous kiln though that of repairs is greater than with intermittent kilns.

Very prolonged soaking is difficult to secure in tunnel kilns as their length is increased by, about

2 ft. for each additional hour of the soaking period. Thus, to ensure 24 hours' soaking the length of the kiln must be increased by 96 ft. This would involve serious mechanical difficulties.

The statement is often made that users of refractory materials will not pay the price necessary to ensure adequate "soaking"; this is largely the case in many industries, though the wiser users are now willing to pay suitable prices when they are satisfied that the goods are of correspondingly greater durability for their particular purpose.

The enormous increase in the durability of glass-melting pots which have been subjected to prolonged heating at 1400° C. before use is another instance of the benefit derived from "soaking," which is too little recognized by glass manufacturers.

End of Burning.

The end of the burning is reached—

(a) When all the shrinkage or expansion has ceased, or when the rate of change is so low that it is considered unnecessary to prolong the heating. It is tested by measuring the height of the bricks in the kiln at various times during the burning and so noting the expansion or shrinkage.

This is the basis of the stipulation in some specifications that, on reheating, the goods must not change in volume by more than a prescribed amount (p. 22).

(b) When the articles have attained a pre-arranged temperature and have been maintained at that temperature for a suitable time. The temperature

realized varies enormously in different works; the values given in Table VI are typical.

TABLE VI.—FINISHING TEMPERATURES FOR BURNING
REFRACTORY ARTICLES.

		Sege Cone.	Tempera- ture °C.	Tempera- ture °F.
Fireclay and Grog bricks	British	5-12	1360-1350	2456-2462
" " " "	German	9-16	1280-1460	2336-2660
Silica bricks*	British	9-14	1280-1410	2336-2570
" " " "	American	10-20	1300-1580	2372-2876
" " " "	French	10-17	1300-1480	2372-2696
Semi-silica and Ganister brick	British	8-14	1260-1410	2282-2570
Magnesia bricks	British	12-18	1350-1500	2462-2732
" " " "	Austrian	27-36	1610-1790	2930-3254
Bauxite bricks	British	8-12	1250-1350	2282-2462
" " " "	French	9-12	1280-1350	2336-2462
Sillimanite bricks	American	14-18	1410-1500	2570-2732
Chromite bricks	British	12-18	1350-1500	2462-2732
Carbon bricks	British	012a-05a	850-1000	1571-1832
Retorts	British	05a-18	1000-1500	1832-2732
Crucibles	British	05a-8	1000-1250	1832-2282
Glass pots†	British	1a-6a	1100-1200	2012-2120

* In the specifications for silica bricks issued by H. Koppers Co. it is directed that "all silica bricks shall be heated to the limit of their expansion, or to a heat affecting Cone 26 and laying Cone 20."

† Glass pots and crucibles are often "baked" rather than burned, the completion of the heat-treatment being in the furnace in which they are used.

In a few works, some of the finishing temperatures are higher than those mentioned, but they are quite exceptional. Probably more English fireclay goods are finished at Cone 9, and silica bricks at temperatures corresponding to Cones 12 to 14, than at any other.

(c) When the requisite internal changes have occurred in the nature of the material, such as the

formation of a sufficient amount of sillimanite (in the case of fireclay), of cristobalite or tridymite (in the case of silica), or periclasé (in the case of magnesia).

Most manufacturers take little, or no interest in these changes, though they are actually far more important than is often realized. This is due to the skill required in making the necessary tests, and to the fact that firebricks are sold on reputation and price rather than on their ascertained properties.

Effect of Heat.

For a more detailed description of the effect of heat on various refractory materials the reader should turn to Chapters I to III. This subject is one which is receiving an increasing attention from scientific men, and whilst many so-called researches have been of little real value, because they were made without sufficient knowledge, they are welcome as showing the assistance which can be rendered by those not directly connected with the refractory materials' industries.

Cooling.

As much care is necessary in cooling some refractory articles, as in burning them, for what may appear to be merely cooling is really an annealing process. Silica especially, undergoes various changes when cooled and it is of great importance that these changes should be properly controlled. The corresponding changes in fireclay and grog have

not been so fully investigated, but they require equal attention on the part of the manufacturer.

The cooling may usually proceed fairly rapidly from the finishing temperature to about 1000° C.—a cherry-red heat—but below this it must proceed very slowly or serious cracks may develop and loss of strength occur. The requisite steadiness in cooling is best secured by means of a continuous kiln in which the air required for the combustion of the fuel is drawn through the cooling goods. The chief drawback to this arrangement—especially if the kiln is rather short—is that the cooling is slowest, where it might be most rapid, and at temperatures below red heat there is a tendency for the cooling to be much too rapid. This may be avoided—in the case of a tunnel kiln—by the use of a cooling or annealing shed, in which the final cooling is effected independently of the kiln.

The rate at which the cooling may safely be effected depends largely on the nature of the goods, the material of which they are made and the size of the kiln. Hollow-ware in a small kiln may be cooled much more rapidly than large blocks in a large kiln, as the mass of material exerts an important influence, particularly in the case of silica and magnesia. Fireclay and grog articles are much less sensitive to sudden cooling, but they should not be cooled too rapidly.

Single or intermittent kilns of average size may usually be allowed to cool from the finishing temperature to a dull red heat in 48 hours—in some cases only 24 hours are needed—but the remainder of the

cooling should usually occupy at least 72 hours, and in many cases 168 hours are desirable.

One of the most foolish things a manufacturer of refractory articles can do is to cool the contents of the kiln too rapidly, in order to please a customer. Such a procedure will seriously reduce the quality of the goods, and whilst this may not be detected immediately it will, eventually, lead to loss of trade.

BURNING HOLLOW-WARE

Crucibles, glass pots, some retorts and many other refractory articles included in the term "hollow-ware" are not burned at the high temperatures recognized as essential for bricks. It is considered sufficient if such hollow-ware is durable under conditions of use, so that the "burning" is really of a preliminary character, and it is completed in the further heat-treatment which these articles undergo immediately before use. Thus, crucibles are "annealed" on or in the furnace fire in which they are to be used, glasshouse pots are subjected to a preliminary heating before being filled with "batch" and many other articles, such as nozzles, stoppers and pipes, undergo their final changes in constitution during the early periods of actual use. It is a matter of financial rather than of technical importance as to whether it is cheaper to purchase a "baked" article, and to complete its heat-treatment immediately before use, or to purchase a fully-burned article which does not require any preliminary precautions. No general rule is

applicable to all cases, but it is obvious that if an article can be rendered quite ready for immediate use under the skilled supervision of the manufacturer, such an article ought to be cheaper in the end—because of its greater durability—than a baked article on which the purchaser has to spend time and skill before he can use it. The subject has many complications but it is worth while for many purchasers to consider it more thoroughly than they have done.

BURNING GROG

Grog is usually burned in shaft kilns resembling those used for lime, but with external fires or gas-firing. The chief requisite is to ensure a sufficiently high temperature, and sufficiently prolonged heating to produce the necessary changes in the material. Where only a comparatively small amount of grog is needed it may be burned in any of the kilns suitable for firebricks, the material being made into rough bricks or clots and burned as bricks.

It is a mistake to cool grog kilns too rapidly as this causes a "shattering" of the material which then has different properties from that which has been properly cooled.

BURNING MAGNESITE •

Magnesite is sometimes burned in shaft kilns, like lime, but more frequently in kilns of the Newcastle type (p. 137), fitted with regenerators and gas-fired. To produce really good dead-burned magnesia a very high temperature (about 1700° C.) is essential,

and unless the material is very impure and consequently inferior in quality, no lower burning temperature will suffice.

Many attempts were made a few years ago to burn magnesite in ordinary coal-fired kilns, but these were never really satisfactory and at the present time there is too great a tendency to add iron oxide or other fluxes, to the magnesite, in order that the magnesite may be burned at a relatively low temperature instead of keeping the material as pure as possible, and burning it at a higher temperature then needed.

The best qualities of dead-burned magnesia yet obtained have been produced by first calcining the magnesia at about 1200° C. in a coal or gas-fired kiln, and afterwards fusing the product in an electric furnace.

CHAPTER VII

THE FINISHED PRODUCTS

THE characteristics and properties of the finished products obtained by the processes, described in Chapters IV to VI, are the same as those of the articles and materials mentioned in Chapters I to III and need not be further detailed. As explained in the Preface, this arrangement has been adopted because the author has found from experience that students are better able to appreciate the purpose of different processes if they are first acquainted with the properties of the finished products.

Durability.

The essential characteristic required of all refractory materials is that they shall possess the utmost durability when in use. It is only too easy to suppose that the chief requisite of a refractory material is its refractoriness, but this is not necessarily the case (p. 1). Other factors may be of greater importance but they are all summed up in the term "durability." This inestimably valuable property is only obtained as a result of the strictest attention to the details of manufacture and of the conditions under which the products are used. The manufacturer and user must co-operate fully if the best results are to be obtained, for neither, alone,

has the necessary knowledge of the details which ensure or prohibit durability.

Some of the properties which a user would like to specify are quite incompatible with others which he regards as essential. Thus, the highest resistance to sudden changes in temperature cannot be obtained simultaneously with the greatest density and resistance to corrosion in a fireclay brick. Full consideration of the relative importance of the various desiderata is, therefore, essential and in this the manufacturer can be of great assistance. Still more useful, both to manufacturer and user, is the consultant expert who has devoted a lifetime to the impartial investigation of the subject, and the best methods of improving the products so as to meet the ever-increasing stringency of the demands of modern requirements.

The maximum durability of any refractory material under given conditions is not a matter of opinion or reputation. To a large extent it cannot ever be deduced from analogy; thus, the addition of either fireclay or silica to magnesia (or *vice versa*) will form a mixture of far less refractoriness than any one of these materials separately. Maximum durability can only be obtained after a detailed investigation of the whole of the conditions involved in that particular case and, to be effective, such an investigation must be made by those accustomed to such work. In such ways, the advisory expert can assist both manufacturer and user, so that by this trinity of effort something approaching to perfection may be best secured.

Selection and Application.

• A full description of the properties of the bricks and other refractory articles required for special purposes, arranged in order of uses, is contained in the chapter on "The Selection and Application of Refractory Materials" in the author's *Refractory Materials ; their Manufacture and Uses*. It cannot usefully be summarized in the space here available.

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The undermentioned "Technical Primers" (Pitman, 2s. 6d. net) are likely to interest readers of this book—

- The Electric Furnace*, by F. J. Moffett.
- Industrial Electric Heating*, by J. W. Beauchamp.
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